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The Flammability Analysis and Time to Reach Lower Flammability Limit Calculations on the Waste Evaporation at 242-A Evaporator

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Abstract: This document describes the analysis of the waste evaporation process on the flammability behavior. The evaluation calculates the gas generation rate, time to reach 25% and 100% of the lower flammability limit (LFL), and minimum ventilation rates for the 242-A Evaporator facility during the normal evaporation process and when vacuum is lost. This analysis performs flammability calculations on the waste currently within all 28 double-shell tanks (DST) under various evaporation process conditions to provide a wide spectrum of possible flammable gas behavior. The results of this analysis are used to support flammable gas control decisions and support and upgrade to Documented Safety Analysis for the 242-A Evaporator.

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AFA	antifoaming agent
BB or bb	barometric breathing
DSA	HNF-14755, *Documented Safety Analysis for the 242-A Evaporator*
DST	double-shell tank
HGR	hydrogen generation rate
LFL	lower flammability limit
SpG	specific gravity
SST	single-shell tank
TOC	total organic carbon
TWINS	Tank Waste Information Network System

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1.0 OBJECTIVE

The 242-A Evaporator is the primary facility at the Hanford Site for waste volume reduction through the evaporation process on low specific gravity (SpG) supernatant waste. This evaluation calculates the gas generation rate, time to reach 25% and 100% of the lower flammability limit (LFL), and minimum ventilation rates for the 242-A Evaporator facility during the normal evaporation process and when vacuum is lost. This analysis performs flammability calculations on the waste currently within all 28 double-shell tanks (DST) under various evaporation process conditions to provide a wide spectrum of possible flammable gas behavior. The results of this analysis are used to support flammable gas control decisions and support and upgrade to HNF-14755, *Documented Safety Analysis for the 242-A Evaporator* (DSA). In addition, a flammability analysis is included for the flammable gas detonation issue using bounding process conditions. This result is used to support an upgrade to the fire hazard evaluation.

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2.0 SUMMARY AND CONCLUSIONS

Analyses for steady-state flammability and time to reach the 25% and 100% of the LFL are performed under barometric breathing and zero ventilation for the 242-A Evaporator facility. Three structures are identified for detailed flammability analysis: the C-A-1 evaporator vessel; its gaseous effluent pathways; and condensate tank TK-C-100. Both normal conditions (i.e., under vacuum) and off-normal (i.e., ambient pressure) conditions were considered.

This analysis adopts the methodology of flammability evaluation developed for the DST and single-shell tank (SST) waste as documented in RPP-8050, *Lower Flammability Limit Calculations for Catch Tanks, IMUSTs, DST Annuli, Pit Structures, and Double-Contained Receiver Tanks in Tank Farms at the Hanford Site*; RPP-5926, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*; and HNF-3851, *Empirical Rate Equation Model and Rate Calculations of Hydrogen Generation for Hanford Tank Waste*. The analysis considered the current waste of all 28 DSTs at various operating temperatures ranging from 120 to 160 °F and concentrated slurry SpG from 1.5 to 1.7. In addition, the times to reach 30 volume percent of hydrogen under no ventilation are calculated for the limiting tank waste of DST 241-AN-102 at temperature of 155 °F and concentrated slurry SpG of 1.6.

From the evaluations, it can be concluded that with waste in the evaporator vessel at ambient pressure and at the bounding operational temperature, the headspace of vessel C-A-1 can reach 25% of the LFL in 1 day for the bounding concentrated tank waste under zero ventilation conditions. Also, during the normal operation at high vacuum and operational temperature the headspace of vessel C-A-1 will have no flammability concern; but the gaseous effluent pathway flammability after the primary condenser may reach 58% of the LFL for current waste from the bounding DST. In addition, the evaluation shows that the condensate tank TK-C-100 will not reach 25% of LFL even when filled to the overflow (85% full) under barometric breathing, but it will reach 25% of the LFL in 432 days under zero ventilation conditions.

Revision 1 of this document:

- Updates the analysis for the addition of antifoaming agents (AFA) to the waste in Chapter 8.0, Section 8.1.
- Documents the flammability analysis for the 242-A Evaporator campaign 07-01 and 07-02 in Appendix D.
- Documents the flammability analysis for the shutdown mode and the startup operation of evaporator process prior to the liquid waste feed in Appendix E.

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3.0 BACKGROUND

The 242-A Evaporator is designed to reduce waste volume and the number of DSTs required to store liquid waste generated at the Hanford Site. The process uses a conventional, forced-circulation, vacuum evaporation system operating at low pressure (approximately 60 torr) and high temperature (approximately 50 °C [122 °F]) to concentrate radioactive waste solutions.

A process flowsheet is shown in Figure 3-1. The waste feed is pumped from feed tank 102-AW through an underground-encased feed line to the 242-A Evaporator and subsequently into vessel C-A-1 for processing. The waste feed is concentrated in vessel C-A-1 to a specified waste concentration creating product slurry (at a target SpG) and water (plus other gases) vapor.

The slurry is transferred from the 242-A Evaporator through underground-encased piping to 241-AW-A or 241-AW-B valve pits in the 241-AW Tank Farm. The slurry is routed to other DSTs in the 200 East Area. Process offgases and water vapor are passed through one primary and two secondary condensers, creating the process condensate and a gaseous effluent. Gaseous effluents are filtered and released to the environment from the vessel ventilation exhaust system. Process condensate is collected in condensate collection tank TK-C-100 and pumped directly to the Liquid Effluent Retention Facility via the P-C-5000 transfer line or used in the process condensate recycle system.

In this flammability analysis, two major components, Evaporator Vessel C-A-1 and Condensate Collection Tank TK-C-100, are identified to be evaluated under both normal and off-normal conditions. In the normal condition, full operation is defined as when the waste is fed into evaporator vessel under low vacuum (pressure ranging 40 to 80 torr) and the boiler heating the waste (temperature ranging 120 to 150°F). The off-normal condition is defined as losing vacuum condition (i.e., ambient pressure) while the waste still remains in the system. Waste recirculation without vacuum, unexpected system shutdown during the evaporation process, or system shutdown after the evaporation process are considered off-normal conditions.

Under normal conditions, the water vapor along with any flammable gas (such as hydrogen, methane and ammonia) that is generated in the headspace of C-A-1 is passed through the condensers to the vessel ventilation exhaust system or process condensate. However, during this normal low-vacuum operation, air is introduced into the system through in-leakage right after the primary condenser E-C-1. This in-leakage is used to control the pressure of vacuum by adjusting the flow rate of air to the system. The air-flammable gas mixture is created after the air is introduced under the normal operation. For the off-normal condition, after a short transition from vacuum condition, the system is under ambient pressure. Flammability analysis on C-A-1 and its gaseous effluent pathway is performed under the normal and off-normal operating condition.

For the condensate tank TK-C-100, the major contents are the condensate water plus soluble gas ammonia, which will produce flammable gas in the headspace. A flammability analysis on TK-C-100 was performed.

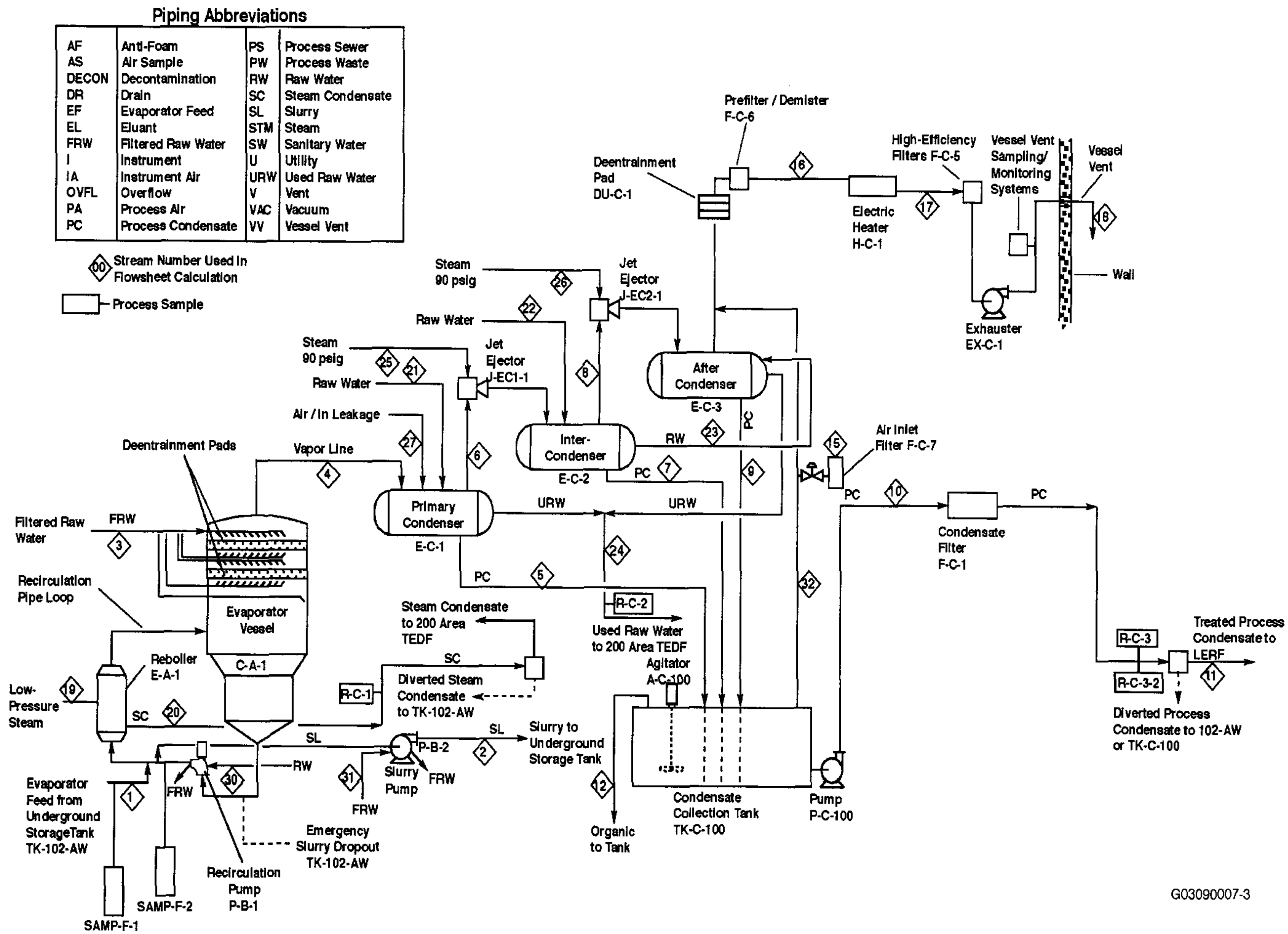


Figure 3-1. 242-A Evaporator Process Flowsheet (Taken from HNF-14755).

4.0 INPUT DATA

The steady-state flammability evaluations use the same methodology and spreadsheet developed for RPP-8050. The required input data for the spreadsheet includes the unit gas rates, waste properties, and the dimensions and properties of the tank containing the waste. The unit rate of gas generation and gas transport properties for waste from all 28 DSTs at various temperatures and targeted slurry SpG are calculated using the spreadsheet developed for RPP-5926.

4.1 WASTE PROPERTIES

The input data to calculate the unit gas generation rate and gas transport properties of waste under current conditions for the 28 DSTs is taken from RPP-5926, Rev. 5, Appendix B, Table B-1, and Appendix C, Table C-1, and are listed in Appendix A, Table A-1. The ammonia data was updated from the Tank Waste Information Network System (TWINS) database in May 2006. The available ammonia data are compiled and listed in Appendix A, Table A-2.

To convert the input data for unit gas rates and gas transport properties calculation from the raw waste condition to the condition of targeted slurry SpG, the following model equations are derived.

Assume the volume of water lost through evaporation is additive with the waste volume. After water is lost through evaporation, the slurry volume is reduced from Vo to V, the slurry density ρ, as the balance of mass, can be expressed as follows (Equation 4-1):

$$\rho = \left[\frac{\rho_0 V_0 - \rho_w (V_0 - V)}{V} \right] \tag{4-1}$$

where ρ_0 and ρ_w are the density of initial slurry density and water density, respectively.

Now define the evaporation concentrating ratio C_R as V_0/V. It can be expressed in terms of the densities by rearranging Equation 4-1 to obtain the expression of V_0/V as follows (Equation 4-2):

$$C_R = \frac{V_0}{V} = \frac{\rho - \rho_w}{\rho_0 - \rho_w} \tag{4-2}$$

The chemical concentration after evaporation concentration can be expressed in terms of initial chemical concentration and densities as Equation 4-3:

$$C = \frac{C_0 V_0}{V} = C_0 \frac{\rho - \rho_w}{\rho_0 - \rho_w} \tag{4-3}$$

Note that volatile chemicals such as ammonia will not be concentrated as above but are governed by Henry's Law reaching the equilibrium between liquid and gas phase. For the radionuclide, since its raw input data is in the unit of micro curie per gram, thus the radionuclide concentration N can be expressed as Equation 4-4:

$$N = \frac{N_0 \rho_0 V_0}{\rho V} = N_0 \frac{\rho_0 (\rho - \rho_w)}{\rho(\rho_0 - \rho_w)} \tag{4-4}$$

where N_0 is the initial radionuclide concentration.

The weight fraction of water W can be derived as follows (Equation 4-5):

$$W = \frac{W_0 \rho_0 V_0 - \rho_w (V_0 - V)}{\rho V} = \frac{\rho_w}{\rho} + \left(\frac{\rho W_0 - \rho_w}{\rho} \right) \frac{\rho - \rho_w}{\rho_0 - \rho_w} \tag{4-5}$$

where the W_0 is the initial weight fraction of water. For a given initial SpG of the supernatant waste and the targeted concentrated slurry SpG, the final chemical concentration (nonvolatile), radionuclide, and weight fraction of water can be calculated at the targeted slurry SpG using Equations 4-1 through 4-5.

The input data from Tables A-1a, A-1b, A-1c, and A1-d, are converted to the target slurry SpG of 1.6 using Equations 4-1 through 4-5 and the results are listed in Appendix A, Tables A-3a, A-3b, A-3c. The ammonia is volatile and its concentration remaining in the liquid is governed by the equilibrium between liquid and gas phases. From the sample results comparing the concentration of feed and target slurry, the slurry remains 10 to 21% of the feed ammonia. In the off-normal condition calculations, 30% is used as a bounding ammonia concentration.

4.2 FACILITY DIMENSIONS

The dimensions of the facility are needed to determine the headspace volume, surface area, and wetted surface of the system. Figure 4-1 is a drawing of the evaporator vessel C-A-1 and its gaseous effluent pathway referenced in the dimension calculations. The layout of evaporator vessel can be broken down into seven parts: top head (A), upper shell (B), upper cone (C), lower shell (D), lower cone (E), recirculation (F), 42-in. pipeline (G), primary condenser (H).

Figure 4-1. Layout of Evaporator Vessel C-A-1 and Its Gaseous Effluent Pathway for Dimensions Calculation.

A. Top Head

B. Upper Shell

C. Upper Cone

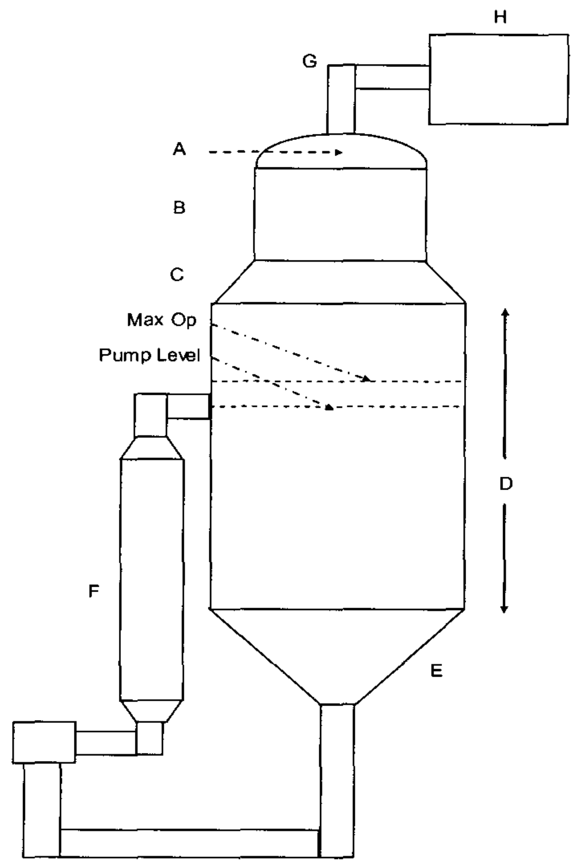
D. Lower Shell

E. Lower Cone

F. Recirculation

G. 42-in. Pipeline

H. Primary Condenser



Detail dimensions of the evaporator vessel are given in RPP-18465, *Technical Basis for the 242-A Evaporator Operating Specifications*. Tables 4-1 and 4-2 list the information for the evaporator vessel and the extended headspace volume from the gaseous effluent pathway, respectively.

Table 4-1. Dimensions, Surface Area and Volume of Evaporator Vessel C-A-1. (2 sheets)

Parts	Description	Values[a]	Units
A	Top head volume	213,906	cubic inch[c]
		926	gallon
	Wet surface area	18,265	square inch[b]
E	Radius of base for lower cone	83.625	inch
	Radius of top for lower cone	13.625	inch
	Height of lower cone	121.25	inch
	Lower cone surface area	43,104	square inch[b]
	Lower cone volume	1,056,181	cubic inch[c]
		4,572	gallon

Table 4-1. Dimensions, Surface Area and Volume of Evaporator Vessel C-A-1. (2 sheets)

Parts	Description	Values[a]	Units
C	Radius of base for upper cone	83.625	inch
	Radius of top for upper cone	68.625	inch
	Height of upper cone	26	inch
	Upper cone surface area	14,428	square inch[b]
	Upper cone volume	474,876.6	cubic inch[c]
		2,056	gallon
D	Inner diameter of lower shell (cylinder)	167.25	inch
	Height of lower shell[b]	216	inch
	Lower shell volume	4,745,433	cubic inch[c]
		20,543	gallon
B	Inner diameter of upper shell (cylinder)	137.25	inch
	Height of upper shell	96	inch
	Upper shell volume	1,420,319	cubic inch[c]
		6,149	gallon
I	Length of nozzle #29	20.75	inch
	Inner diameter of nozzle #29	27.25	inch
	Nozzle #29 volume	12,102	cubic inch[c]
		52	gallon
	Length of nozzle #2	12.19	inch
	Inner diameter of nozzle #2	41.25	inch
	Nozzle #2 volume	16,291	cubic inch[c]
		71	gallon
F	Recirculation pipe volume[c]	794,586	cubic inch[c]
		3,440	gallon
	Recirculation pipe surface	98,698	square inch[b]
Total volume of C-A-1		8,733,694	cubic inch[c]
		5,054	cubic feet
		37,808	gallon

Notes:

[a]The dimension information is taken from RPP-18465, unless otherwise noted.

[b]The height of lower shell is taken from RPP-18465.

[c]The volume of recirculation is taken from RPP-18465.

RPP-18465, 2007, *Technical Basis for the 242-A Evaporator Operating Specifications*, Rev. 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table 4-2. Extended Vapor Space Volume Beyond Vessel C-A-1 Headspace.

Parts	Description	Values	Units
G	Diameter of 42-in. pipeline between vessel and primary condenser*	42	inch
	Length of 42-in. pipeline*	20	feet
	Volume of 42-in. pipeline*	192	cubic feet
H	Diameter of primary condenser**	85	inch
	Length of primary condenser**	12	feet
	Total volume of primary condenser**	473	cubic feet
	Diameter of baffle tube inside condenser	0.75	inch
	Diameter of baffle tube inside condenser	12	feet
	Total volume of 2,950 pieces of baffle tube within condenser for raw water which should be excluded in the extended head space volume calculation**	109	cubic feet
Total volume of extended vapor space		557	cubic feet

Notes:

The volume of the pathway after the primary condenser is small and is neglected in the calculation.

* From drawings H-2-69339, H-2-69340, and H-2-69343.

**From certified vendor information [CVI]: file number 20253.

H-2-69339, 1976, *Piping Arrangement Evaporator Room Plans*, Rev. 2, Vista Engineering, U.S. Atomic Energy Commission, Richland Operations Office, Richland, Washington.

H-2-69340, 1977, *Piping Arrangement Evaporator Room Sections*, Rev. 3, Vista Engineering, U.S. Atomic Energy Commission, Richland Operations Office, Richland, Washington.

H-2-69343, 1988, *Piping Arrangement Condenser Room Section*, Rev. 6, Vista Engineering, U.S. Atomic Energy Commission, Richland Operations Office, Richland, Washington.

The maximum operational volume is 26,000 gal (OSD-T-151-00012, *Operating Specifications for the 242-A Evaporator*, Sec. 2.2.1), which is 15.654 ft from the bottom of the lower shell (component D in Figure 4-1). Given the total volume of C-A-1 is 37,808 gal (5,054 ft^3) from Table 4-1, the volume of headspace in C-A-1 is 11,808 gal (1,179 ft^3). The waste surface area, which is the surface area of lower shell, is 152 ft^2. The required wet surface area, which is the surface area below the waste surface of the maximum operation level, is 1,839 ft^2 including the surface area of components E and F, and part of component D. Furthermore, since there is no gate between the headspace and the rest of gaseous effluent pathway, in the calculation the headspace of C-A-1 are expanded to include the 42-in. pipeline (component G) and the vapor space of primary condenser (component H). The volume of gaseous effluent pathway after primary condenser is small and is neglected in the calculation. Table 4-2 provides the dimension information for the extended vapor space beyond vessel C-A-1 and shows the total extra headspace volume is 557 ft^3. In the flammability calculation, the total headspace volume used in the calculation becomes 2,135 ft^3 and the equivalent filled fraction becomes 0.62 instead of 0.69.

The second facility to be evaluated is condensate tank TK-C-100. It is a straight cylinder with dishes at the top and bottom. The dimensions and calculated volume are given in Table 4-3.

Table 4-3. Dimensions, Volume, and Surface Area of Condensate Tank TK-C-100.

Description	Values	Unit
Diameter of the straight cylinder	14	feet
Height of the straight cylinder	14	feet
Thickness of the wall	0.31	inch
Height of the dish (estimated)	2.8	feet
Volume of vertical straight cylinder	2139	cubic feet
Estimated volume of dish bottom	285.2	cubic feet
Estimated volume of dish top	285.2	cubic feet
Total tank volume	2710	cubic feet
Surface area of dish (estimated as cylinder)	275.5	square feet
Waste surface area of straight cylinder	152.8	square feet
Straight cylinder above overflow	108.2	cubic feet
Total volume above overflow	393.4	cubic feet
Fraction of volume above overflow	0.15	

Note:

The tank dimension is taken from H-2-40704, 1975, *Class II Vessel 14 Feet 0 Inch X 14 Feet 0 Inch Tank TK-386*, Rev. 4, Kellex Corporation, General Electric Company, Hanford Works, Richland, Washington.

5.0 ASSUMPTIONS

In the unit rate calculation, it is assumed that the methane generation unit rate is 10% of the calculated unit rate of the sum of the radiolysis and thermolysis for hydrogen generation at various tank waste temperatures and moisture contents. In this assumption to estimate methane generation rate, the corrosion portion of hydrogen generation is omitted from the calculation. This is because the hydrogen generation from corrosion is through water, and water will not generate methane.

The sample results of evaporation campaigns 94-2 (WHC-SD-WM-PE-054, *242-A Campaign 94-2 Post Run Document*) and 05-01 (RPP-RPT-27963, *242-A Evaporator Campaign 05-01 Vapor Emissions Evaluation*, RPP-PLAN-23668, *Process Control Plan for 242-A Evaporator Campaign 05-01*) show the ammonia concentration in the slurry ranging from 10% to 21% of the feed waste. In the flammability calculations for the C-A-1 headspace under ambient pressure, the concentration of ammonia remaining in the evaporator vessel C-A-1 (which is the same as slurry when it reaches steady-state) is conservatively assumed to be 30% of the ammonia concentration in the feed waste. It is believed that the 30% should also be a bounding number during the startup (since the evaporator is initially charged with water and waste is slowly injected after the vessel reaches operating temperature and pressure).

In the flammability calculation for the headspace and gaseous effluent of the C-A-1 under vacuum condition, it is conservatively assumed that only 10% of the ammonia in the feed remains in the vessel and 90% goes to the headspace; and 8.6% of the 90% of the feed ammonia remains in the vapor phase after primary condenser (HNF-14755, Appendix 2B, 8.6% is the ratio of Stream 6 [vapor line after primary condenser] and Stream 4 [vapor line before primary condenser])

It is assumed that the volume percent of the LFLs for each flammable gas at the high vacuum is the same as at 1 atmosphere.

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6.0 METHOD OF ANALYSIS

In order to help establish flammable gas control criteria, a total of 28 DSTs are modeled and analyzed to characterize the flammable gas behavior of the current liquid waste under the evaporation process in the 242-A Evaporator. The flammability level of the waste is the net contribution from all flammable gases accumulated from the various contributors (e.g., high ammonia concentration, radionuclide inventory, high TOC) from each gas. Therefore, analyzing the waste from all 28 DSTs provides a wide spectrum of waste profiles for understanding the different causes of the flammable gas behavior.

This flammability analysis models the following cases using all 28 DST current wastes.

1. The steady-state flammability level and time to reach specified level of LFL for the evaporator vessel C-A-1 and its gaseous effluent pathway when the system contains waste under the ambient pressure during the unexpected system shutdown, waste recirculation mode, or after the evaporation process has been completed. Flammability calculations are conducted at waste temperatures of 120, 130, 140, 150, 155, 160 °F with targeted slurry SpG of 1.5, 1.55, 1.6, and 1.7. In the calculations, the concentration of ammonia remaining in the evaporator vessel C-A-1 is conservatively assumed to be 30%.

2. The flammability level and time to reach a specified level of LFL for the condensate tank TK-C-100 at various filled levels up to the overflow line. The system is always running under ambient pressure. The analysis calculates the flammability in 10% increments from 10% filled to about 85% filled under waste temperature of 85 °F.

3. The flammability level of the headspace of evaporator vessel C-A-1 and the gaseous effluent pathway after C-A-1 vessel during the normal operation under low vacuum conditions. Flammability calculations are conducted for the gaseous effluent pathway just past the primary condenser for the case of 155 °F, SpG of 1.6 and 7.74% ammonia in the feed (which is the product of 90% from the feed and 8.6% surviving after the primary condenser).

For a system under ambient pressure, the flammability analysis uses the methodology developed for the steady-state flammability analysis on 177 DSTs and SSTs and miscellaneous secondary tanks and structures at the Hanford Site. The methodology is documented in detail in HNF-3851, RPP-5926, and RPP-8050, and the equations pertinent to this analysis are described in Sections 6.1 through 6.4. For the system under a low pressure vacuum condition, this flammability analysis uses a simplified and bounded approach rather than a sophisticated and tedious approach for the dynamic flow condition. Details of this dynamic analysis are given in Section 6.5.

6.1 RATE EQUATIONS FOR HYDROGEN GENERATION

The empirical rate equation for hydrogen generation in Hanford Site waste contains the simulation of thermal reaction, HGR_{thm}, radiolysis of water and organic, HGR_{rad}, and the corrosion process, HGR_{corr}. This rate equation is a function of waste composition (TOC, Al^{+3}, NO_3^-, NO_2^-, OH^- and Na^+), radiation dose, temperature, liquid fraction, and tank wetted area. Both the thermal and organic radiolysis rates follow Arrhenius behavior with a derived activation energy. The equation for the hydrogen generation rate (HGR) in the units of moles per kilogram per day can be summarized as follows (Equation 6-1):

$$HGR = HGR_{thm} + HGR_{rad} + HGR_{corr} \tag{6-1}$$

where:

$$HGR_{thm} = a_{thm} \times (r_f \times [TOC]) \times [\mathrm{Al}^{+3}]^{0.4} \times L_f \times \exp^{(-E_{thm}/RT)}$$

$$HGR_{rad} = [(G(\mathrm{H}_2)_{H2O}^{\beta/\gamma} + G(\mathrm{H}_2)_{ORG}^{\beta/\gamma}) \times H_{Load}^{\beta/\gamma} + (G(\mathrm{H}_2)_{H2O}^{\alpha} + G(\mathrm{H}_2)_{ORG}^{\alpha}) \times H_{Load}^{\alpha}] \times L_f \times CF_1$$

$$HGR_{corr} = R_{corr} \times E_{H_2} \times A_{wetted} / M_{\tan k} \times CF_2$$

with:

$$G(\mathrm{H}_2)_{ORG}^{\beta/\gamma} = a_{rad} \times \exp^{(-E_{rad}/RT)} \times (r_f \times [TOC])$$

$$G(\mathrm{H}_2)_{H2O}^{\beta/\gamma} = \frac{0.32}{1 + 2.4[\mathrm{NO}_3^-] + 0.62[\mathrm{NO}_2^-] + 0.31[\mathrm{Na}^+]_{ex}^2} + \frac{0.13}{1 + 139[\mathrm{NO}_3^-] + 54[\mathrm{NO}_2^-]}$$

$$G(\mathrm{H}_2)_{ORG}^{\alpha} = 0.5 \times a_{rad} \times \exp^{(-E_{rad}/RT)} \times (r_f \times [TOC])$$

$$G(\mathrm{H}_2)_{H2O}^{\alpha} = \frac{1.05}{1 + 2.4[\mathrm{NO}_3^-] + 0.63[\mathrm{NO}_2^-]} + \frac{0.35}{1 + 3900[\mathrm{NO}_3^-] + 1400[\mathrm{NO}_2^-]}$$

and:

E_{thm}	=	89.6 kJ/mole, the activation energy for the thermal reaction
a_{thm}	=	3.94 E+09 mole/kg-day, pre-exponential factor of the thermal rate
E_{rad}	=	48.8 kJ/mole, activation energy in organic radiolysis, G
a_{rad}	=	1.11 E+07 H_2/100 eV, the pre-exponential term in organic radiolysis, G
r_f	=	0.6 for DSTs and 0.3 for SSTs (unitless), the TOC reactivity coefficient Note: The r_f = 0.3 for SSTs is an average value from the tanks tested. If the tank has a high fraction of energetic organic compounds, the r_f can be adjusted to as high as 0.6.
R	=	8.314 J/mole/K, gas constant
R_{corr}	=	6.0 E-08 for DSTs and 2.4 E-07 for SSTs ($ft^3/min/ft^2$), corrosion coefficient
E_{H2}	=	the hydrogen generation efficiency coefficient from corrosion is 20% if $[NO_3^-]$, $[NO_2^-]$, and $[OH^-] > 0.1$, otherwise it is 50%.

[TOC] = total organic carbon concentration in the liquid waste (wt%)
Note: Insoluble energetic organic compounds (excluding oxalate) in the solid layer should be considered case by case when data are available
$[Al^{+3}]$ = aluminum ion concentration in liquid waste (wt%)
$[NO_3^-]$ = nitrate ion concentration in the liquid waste (moles/L)
$[NO_2^-]$ = nitrite ion concentration in the liquid waste (moles/L)
$[Na^+]_{ex}$ = concentration of sodium minus nitrate and nitrite concentration in liquid waste (moles/L)
$H_{load}^{\beta/\gamma}$ = total heat load of the tank from beta/gamma (Watt/kg)
H_{load}^{α} = total heat load of the tank from total alpha (Watt/kg)
L_f = liquid weight fraction in the waste (unitless)
T = temperature of waste (K)
A_{wetted} = area of steel exposed to moisture-containing waste (ft^2)
M_{tank} = total mass in the waste (kg)
CF_1 = conversion factor from (H_2/100 eV)(watts/kg) to (mole/kg-day)
CF_2 = conversion factor from (m^3/kg-min) to (mole/kg-day).

6.2 EQUILIBRIUM GAS TRANSPORT RATE

For a highly soluble gas, such as ammonia, the gas release rate from liquid waste is not a constant, but depends on the material transport properties and the ammonia concentration gradient between the liquid and vapor phases and appropriate Henry's Law constants. The Henry's Law constant is a function of temperature in pure water. In mixed salt solutions, Henry's Law constants are functions of both temperature and the concentrations of the ions in the solution. For a closed system, the Henry's Law in a mixed solution describes the relationship of a soluble gas in the liquid and vapor phases as provided in Equation 6-2:

$$C_l = K_H \cdot P_g \tag{6-2}$$

With $K_H = K_H{}^o \cdot 10^{-\sum_i (h_i + h_g)\cdot C_i}$

and $K_H{}^o = e^{-8.0964+3917.5/T-0.00314T}$

where:

C_l = ammonia concentration in the liquid phase (kg-mole/m^3)
K_H = Henry's Law constant (kg-mole/m^3-atm)
P_g = partial pressure of the ammonia (atm).
$K_H{}^o$ = Henry's Law constant in the pure water (kg-mole/m^3-atm)
h_i = Ionic dependent coefficient
h_g = gas specific constant for ammonia

C_i = ion concentration in the solution.
T = temperature of waste (K)

This modified equation to calculate Henry's Law constant in a mixed solution is documented in "The Estimation of Gas Solubility in Salt Solutions at Temperature from 273 K to 363 K," AICHE Journal (Weisenberger and Schumpe 1996). However, the Weisenberger and Schumpe (1996) formula is good only for the solution up to 5 M. RPP-4941, *Methodology for Predicting Flammable Gas Mixtures in Double-Contained Receiver Tanks*, reported Henry's Law constants for DST 241-SY-101 simulant waste at different dilution conditions and temperatures. This study covers solution concentrations ranging from 5 to 21 M at temperatures of 20 °C to 70 °C.

Consider the two-film theory of mass transfer. The ammonia release will encounter the resistance from two films, the liquid film and the gas film, between the bulk liquid and bulk vapor phases. The release rate is proportional to the difference between the ammonia liquid concentration and the ammonia vapor concentration before reaching equilibrium. It also is proportional to the mass transport coefficient, h, and the effective area, A. Therefore, the release rate can be derived as provided in Equation 6-3:

$$R_g = h \cdot A \cdot (C_l - K_H \cdot P \cdot v \cdot C_g) \qquad (6\text{-}3)$$

where:

R_g = gas release rate (kg-mole/day)
h = overall mass transport coefficient from liquid to vapor (m/day)
A = effective area for the transport (m^2)
C_l = current ammonia concentration in liquid (kg-mole/m^3)
P = dome space total pressure (atm)
v = specific molar volume of gas in the dome space (m^3/kg-mole)
C_g = current ammonia concentration in the dome space (kg-mole/m^3)
K_H = Henry's Law constant (kg-mole/m^3-atm).

As Equation 6-3 shows, the ammonia gas release rate clearly is a function of the ammonia concentrations in the liquid and vapor phases and the Henry's Law constant for ammonia in the solution. In the two-film-theory of mass transfer, the overall mass transport coefficient, h, contains the transport coefficient h_l for liquid diffusing through the liquid film and h_g for the gas diffusing through the gas film. Equations of the calculated h are described in detail in RPP-4941.

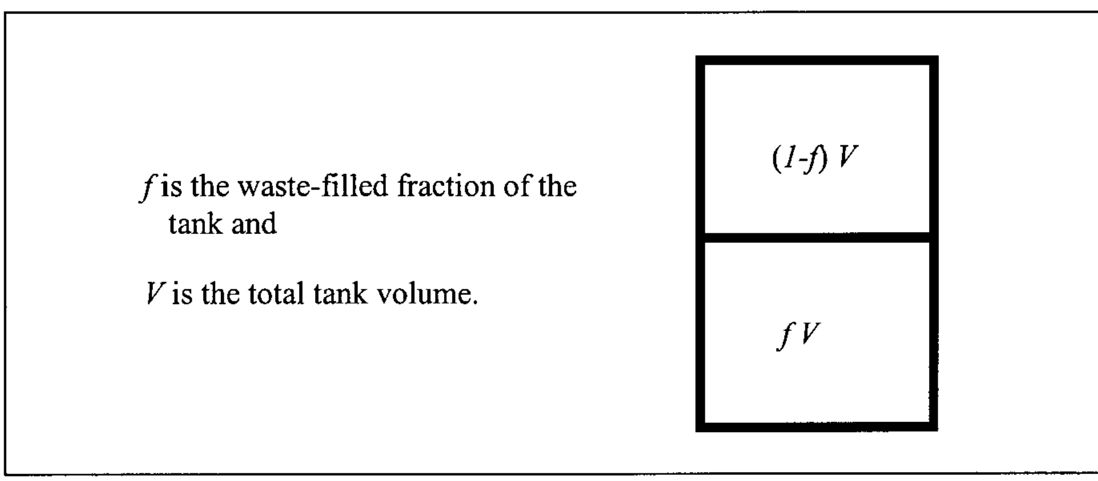
6.3 TIME-DEPENDENT GAS CONCENTRATION MODEL

A time-dependent gas concentration model for the tank dome space was developed and is documented in RPP-5926. The model calculates the gas concentrations for hydrogen, ammonia, and methane at a given time under a given ventilation condition. Hydrogen, the major flammable gas, along with ammonia and methane, are observed in the tank farms. Hydrogen is insoluble and observed mostly in the tank dome space. In the model, the gas release rates of hydrogen are calculated with the HGR model (HNF-3851) as summarized in a previous section.

Ammonia is very soluble and found mainly in the liquid waste. In the model, the gas transport of ammonia is handled with the equilibrium model of mass transport. In addition, in the model, the gas release rates of methane and nitrous oxide (as oxidizer observed in the mixture) are derived from the steady-state concentration and ventilation rate in the tank dome space.

In order to model the flammability parametrically in terms of waste fraction, it is convenient to convert the time gas concentration model from the volume-based to waste-filled fraction system, as documented in RPP-8050 and summarized as follows. In brief, the waste volume can be expressed in terms of the waste-filled fraction, f, of the total tank volume, V, as $f\,V$, and the tank dome space volume is expressed as, $(1-f)\,V$, as shown in Figure 6-1.

Figure 6-1. The Model of Waste Volume Fraction.



For the insoluble flammable gases, by solving the differential equation of the mass balance in the tank headspace, a time-dependent gas concentration at time t in terms of waste-filled fraction, f, $[C_g](t)$, in the units of volume percent is given as Equation 6-4:

$$[C_g](t) = [C_g](t_0)\exp(-b\cdot t) + \left[\frac{f}{b\cdot(1-f)}\right] U_g[1-\exp(-b\cdot t)] \tag{6-4}$$

Where:

f	=	waste-filled fraction (unitless)
b	=	ventilation rate constant of 0.45% per day for barometric breathing or the decay parameter from venting in general which is the ratio of vent rate and headspace volume (1/day)
$[C_g](t_o)$	=	initial gas concentration at time t_o (kg-mole/m^3)
t	=	time (days)
U_g	=	unit gas release rate per unit waste volume (kg-mole/m^3-day)

For steady state, the first term of Equation 6-4 drops to zero, and the factor of $[1- e^{(-bt)}]$ becomes 1, and the gas concentration becomes Equation 6-5:

$$[C_g]_{ss} = \left[\frac{f \cdot U_g}{b \cdot (1-f)}\right] \times 100\% \tag{6-5}$$

Under zero ventilation, Equation 6-4 becomes the following:

$$[C_g]_{\%}(t) = [C_g]_{\%}(t_0) + \left[\frac{f}{(1-f)} \cdot U_g \cdot t\right]_{\%} \tag{6-6}$$

For soluble flammable gas, the time-dependent gas concentration is given as Equation 6-7:

$$[C_g]\,(t) = [C_g]\,(t_0)\exp(-k_1 \cdot t) + \left[\frac{k_2}{k_1}\right][1 - \exp(-k_1 \cdot t)] \tag{6-7}$$

with $\quad k_1 = [b \cdot (1-f) + h \cdot R_{sv} \cdot f \cdot K_H \cdot P \cdot v]/(1-f)$

and $\quad k_2 = [h \cdot R_{sv} \cdot f \cdot C_l]/(1-f)$

where:

h	=	overall mass transport coefficient from liquid to vapor (m/day)
f	=	waste-fill fraction
R_{sv}	=	ratio of surface area and waste volume
C_l	=	ammonia concentration in liquid (kg-mole/m^3)
C_g	=	ammonia concentration in a tank dome space (kg-mole/m^3)
P	=	tank dome space total pressure (atm)
v	=	specific molar volume of gas in the tank dome space (m^3/kg-mole)
K_H	=	Henry's Law constant (kg-mole/m^3-atm).

The steady-state gas concentration becomes Equation 6-8 for soluble components:

$$[C_g]_{ss} = \left[\frac{h \cdot R_{sv} \cdot f \cdot C_l}{b \cdot (1-f) + h \cdot R_{sv} \cdot f \cdot K_H \cdot P \cdot v}\right] \tag{6-8}$$

Under zero ventilation, Equation 6-9 is the soluble component equivalent to Equation 6-7:

$$[C_g](t) = [C_g](t_0)\exp(-g_1 \cdot t) + \left[\frac{g_2}{g_1}\right][1 - \exp(-g_1 \cdot t)] \tag{6-9}$$

with $$g_1 = \frac{f}{(1-f)} \cdot [h \cdot R_{sv} \cdot K_H \cdot P \cdot v]$$

and $$g_2 = \frac{f}{(1-f)} \cdot [h \cdot R_{sv} \cdot C_l]$$

In some cases, particularly when the product of h and A is large, the $g_1 t$ is much greater than one within a few days. So the decay rate exp ($-g_1.t$) goes to zero in a few days, thus the vapor concentration is simply the vapor equilibrium concentration C_{eq} with liquid phase as shown in Equation 6-10:

$$C_{eq} = \frac{C_l}{K_H \cdot P \cdot v} \tag{6-10}$$

6.4 FLAMMABILITY LEVEL MODEL CALCULATION

Using the time-dependent gas concentration (Equation 6-4 for insoluble gas or Equation 6-7 for soluble gas) and the Le Chatelier's rule a time-dependent percentage of LFL, $LFL_m(t)$, of the mixture can be calculated as shown in Equation 6-11:

$$LFL_m(t) = \left[\frac{[H_2](t)}{[H_2]_{LFL}} + \frac{[CH_4](t)}{[CH_4]_{LFL}} + \frac{[NH_3](t)}{[NH_3]_{LFL}}\right] \times 100\% \tag{6-11}$$

where:

$[H_2](t)$	=	hydrogen concentration (volume percent) in tank dome space at time t
$[NH_3](t)$	=	ammonia concentration (volume percent) in tank dome space at time t
$[CH_4](t)$	=	methane concentration (volume percent) in tank dome space at time t
$LFL_m(t)$	=	percentage of LFL for the mixture of the flammable gases at time t
$[H_2]_{LFL}$	=	volume percent of hydrogen at its LFL in air alone
$[NH_3]_{LFL}$	=	volume percent of ammonia at its LFL in air alone
$[CH_4]_{LFL}$	=	volume percent of methane at its LFL in air alone.

The volume percents of the LFLs ($[H_2]_{LFL}$ = 4%, $[NH_3]_{LFL}$ = 15%, and $[CH_4]_{LFL}$ = 5%) have been established for a fuel-air mixture.

For a given ventilation rate, the time to reach a specified gas concentration under given ventilation conditions can be obtained by rewriting Equation 6-4 and is given as Equation 6-12:

$$t = \frac{\ln\left\{\dfrac{f \cdot U_g - b \cdot (1-f) \cdot C_g(t_0)}{f \cdot U_g - b \cdot (1-f) \cdot C_g(t)}\right\}}{b} \qquad (6\text{-}12)$$

Similarly, for soluble gases, the time to reach a specified gas concentration under a given ventilation condition can be obtained by rewriting Equation 6-7 and is given as Equation 6-13:

$$t = \frac{\ln\left\{\dfrac{k_2 - k_1 \cdot C_g(t_0)}{k_2 - k_1 \cdot C_g(t)}\right\}}{k_1} \qquad (6\text{-}13)$$

with $k_1 = \lfloor b \cdot (1-f) + h \cdot R_{sv} \cdot f \cdot K_{_{ll}} \cdot P \cdot v \rfloor / (1-f)$

and $k_2 = [h \cdot R_{sv} \cdot f \cdot C_l] / (1-f)$

However, the time to reach a specified flammability limit of the mixture was not calculated explicitly. A customized macro function in Excel[1] using Visual Basic Application[2], based on Equation 6-12 for an insoluble gas and Equation 6-13 for a soluble gas, was developed to calculate the time to reach a specific flammability level. For zero ventilation condition, the time to 25% and 100% of the LFL is simply the accumulative time to the specified flammability level, which is straightforward.

It is worthwhile to determine the minimum ventilation rate required to maintain the tank dome space below 100% LFL. A steady-state flammability level can be expressed as shown in Equation 6-14:

$$LFL_{ss} = \left[\frac{[H_2]_{ss}}{[H_2]_{LFL}} + \frac{[NH_3]_{ss}}{[NH_3]_{LFL}} + \frac{[CH_4]_{ss}}{[CH_4]_{LFL}}\right] \times 100\% \qquad (6\text{-}14)$$

where:

LFL_{ss}	=	steady-state percentage of the LFL for the mixture of the flammable gases in the tank headspace
$[H_2]_{ss}$	=	steady-state hydrogen concentration (volume percent)
$[NH_3]_{ss}$	=	steady-state ammonia concentration (volume percent)
$[CH_4]_{ss}$	=	steady-state methane concentration (volume percent).

[1]Excel is a registered trademark of Microsoft Corporation, Redmond, Washington.

[2]Visual Basic is a registered trademark of Microsoft Corporation, Redmond, Washington.

The steady-state concentration can be calculated using Equations 6-5 and 6-8 for the insoluble gases, H_2 and CH_4, and the soluble gas, NH_3, respectively. These steady-state gas concentrations are ventilation-rate dependent. The minimum ventilation rate to maintain the flammability under 100% LFL can be calculated using Equation 6-14 by setting the steady-state concentration at a specified percentage of the LFL (e.g., 100%). Again, the ventilation rate is embedded in the equation, and a customized macro function in Excel using Visual Basic code was developed to calculate the minimum ventilation to reach the specified flammability level.

6.5 FLAMMABILITY ANALYSIS FOR THE PROCESS UNDER LOW VACUUM

Under the normal evaporation process, the water vapor along with flammable gases such as hydrogen, methane, and ammonia are generated from the liquid waste in the vessel C-A-1 into the headspace, and continuously removed by the low vacuum condition through the gaseous effluent pathway to vessel vent exit. This analysis simply considers the mass balance of the vapor components in the vapor flow at various stages using the flow rates of each input stream. Once the rates of all vapor components are estimated in the flow, the flammability of the vapor mixture can be calculated.

For hydrogen and methane, during normal operation, the highest generation rate occurs when the evaporation process reaches the steady-state slurry production mode, i.e., when the waste is concentrated at the targeted SpG (1.4-1.6). This is evident since a plot of the time to LFL against SpG is linear with a negative slope (Figure 8-1). The gas generation rate in moles per minute can be calculated for given waste conditions (e.g., the concentration of chemicals and radionuclide, the waste temperature, wt% water at the targeted slurry SpG) using the rate equation model given in Section 6.2. The method to evaluate a waste condition at a targeted slurry SpG is given in Section 4.1.

The ammonia is soluble and its transport mechanism or release rate is governed by thermodynamic equilibrium between the liquid and vapor phase and the mass transfer discussed in Section 6.2. The equilibrium model of ammonia transport described in Section 6.3 is not validated for the system under the vacuum condition. The approach here is to obtain the ammonia release mass rate (moles per minute) to the headspace by calculating the difference of mass rate between the feed and slurry steams as follows (Equation 6-15).

$$M_{NH3}^{headspace} = (R_{feed} \times C_{feed}^{NH3}) - (R_{slurry} \times C_{slurry}^{NH3}) \qquad (6\text{-}15)$$

where:

$M_{NH3}^{headspace}$		mass flow of ammonia in the headspace
R_{feed}	=	flow rate of feed stream
C_{feed}^{NH3}	=	ammonia concentration in feed stream
R_{slurry}	=	flow rate of slurry stream
C_{slurry}^{NH3}	=	ammonia concentration in slurry stream.

The slurry ammonia concentration uses conservatively 10% of the feed ammonia concentration based on the sample results (see Section 5.0). The flow rate of each steam used in this calculation is from the high side of the possible rates as given in Table 2-2 of HNF-14755. The water mass rate into the headspace can be calculated as follows (Equation 6-16):

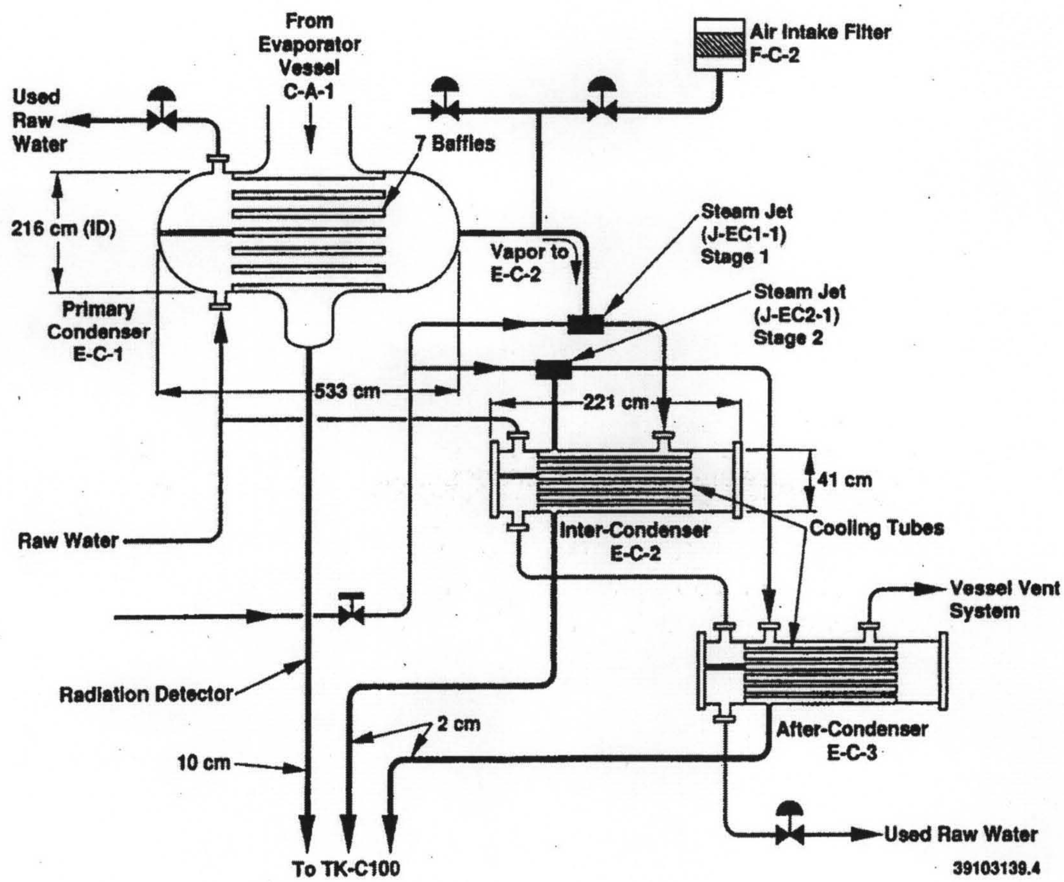
$$M_{H2O}^{headspace} = \{(R_{feed} \times D_{feed} \times Wt\%_{H2O}^{feed}) - (R_{slurry} \times D_{slurry} \times Wt\%_{H2O}^{slurry})\}/18 \qquad (6\text{-}16)$$

where:

$M_{H2O}^{headspace}$	=	mass flow of water in the headspace
D_{feed}	=	density of feed stream
C_{feed}^{NH3}	=	ammonia concentration in feed stream
D_{slurry}	=	density of slurry stream
C_{slurry}^{NH3}	=	ammonia concentration in slurry stream
$Wt\%_{H2O}^{feed}$	=	weight fraction of water in the feed stream
Wt_{H2O}^{slurry}	=	weight fraction of water in the slurry stream.

In the headspace of C-A-1, there is no flammable gas concern because the mixture is mainly water vapor (over 99%) and very little air. Similar conditions apply to the 42-in. pipeline between the C-A-1 and the primary condenser itself. When the vapor gases enter the primary condenser (E-C-1), the majority of water and soluble gas (e.g., ammonia) undergoes condensation and goes to the condensate tank TK-C-100. Only insoluble gases (e.g., hydrogen and methane) of the flammable gas concerned plus a small fraction of water and ammonia remains in the vapor phase after the primary condenser. Figure 6-2 is the diagram of the steam jet ejector and three stages of condensers.

Figure 6-2. Steam Jet Ejector and Three Stages of Condensers (taken from HNF-14755).



As mentioned in Section 3.0, in-leakage air (with filter F-C-2) merges in with the exit effluent gaseous line of primary condenser to adjust the pressure of vacuum system (see Figure 6-2). There is a concern about the flammable gas issue because the air was introduced into the gaseous effluent along with remaining ammonia plus insoluble hydrogen and methane from the original vapor steam after the primary condenser. The in-leakage air mass rate $M_{air}^{effluent}$ (g-mole/min) into the gaseous effluent after the primary condenser can be easily calculated as follows (Equation 6-17):

$$M_{air}^{efflunt} = (R_{in-leakage} / (22.4 \times T_{ambient} / 273) \qquad (6\text{-}17)$$

It is assumed that the mass flow rate of hydrogen and methane after primary condenser is the same as in the headspace. For the calculations, it is also assumed the percent of ammonia remaining in the vapor phase after primary condenser is 8.6% (see Section 5.0) of the ammonia mass rate $M_{NH3}^{headspace}$ (mole/min) in the headspace and given as follows (Equation 6-18):

$$M_{NH3}^{effluent} = 8.6\% \times M_{NH3}^{headspace} \tag{6-18}$$

The ammonia survival ratio is 8.6% right after the primary condenser, and it drops another 40% of the 8.6% after the inter-condenser (HNF-14755, Appendix 2B, Table 2B-1, Stream 6 and 8). The percent of water remaining in the vapor phase after primary condenser is 0.02% (HNF-14755, Appendix 2B, Table 2B-1, Stream 4 and 6) of the water mass rate $M_{H2O}^{headspace}$ (mole/min) in the headspace and given as follows (Equation 6-19):

$$M_{H2O}^{effluent} = 0.02\% \times M_{H2O}^{headspace} \tag{6-19}$$

At the same temperature and pressure, the volume percent concentration of each vapor gas per minute is the same as the g-mole percent concentration and can be calculated as follows (Equation 6-20):

$$[FlamGas]_{(vol\%)} = \left[\frac{M_{FlamGas}^{effluent}}{\sum\limits_{i=Air,H2,CH4,NH3} M_{FlamGas_i}^{effluent}} \right] \times 100\% \tag{6-20}$$

The flammability of gaseous effluent pathway after the primary condenser can be calculated as follows (Equation 6-21):

$$LFL_m = \left[\frac{[H_2]_{vol\%}}{[H_2]_{LFL}} + \frac{[NH_3]_{vol\%}}{[NH_3]_{LFL}} + \frac{[CH_4]_{vol\%}}{[CH_4]_{LFL}} \right] \times 100\% \tag{6-21}$$

where:

$[H_2]$	=	hydrogen concentration (volume percent) in gaseous effluent
$[NH_3]$	=	ammonia concentration (volume percent) in gaseous effluent
$[CH_4]$	=	methane concentration (volume percent) in gaseous effluent
LFL_m	=	percentage of LFL for the mixture of the flammable gases
LFL_{H2}	=	volume percent of hydrogen at its LFL in air alone
LFL_{NH3}	=	volume percent of ammonia at its LFL in air alone
LFL_{CH4}	=	volume percent of methane at its LFL in air alone.

The volume percents of the LFLs ($[H_2]_{LFL}$ = 4%, $[NH_3]_{LFL}$ = 15%, and $[CH_4]_{LFL}$ = 5%) have been established for a fuel-air mixture. It is assumed that the same LFL for each gas applies at the high vacuum condition.

7.0 USE OF COMPUTER SOFTWARE

This case study uses a validated Excel spreadsheet, documented in RPP-5926 and RPP-8050, to calculate the HGRs, the time to 25% and 100% of the LFL, and the minimum ventilation rate. The spreadsheet was verified in compliance with TFC-ENG-CHEM-D-33, *Spreadsheet Verification*, and is documented in spreadsheet verification form SVF-032.

Spreadsheet owner: T. A. Hu

Spreadsheet name: RPP-5926-8050-R4-LFL-CAL-T2-122004.xls

Spreadsheet location: *Hanford\Data\Sitedata* \FlamGas\RPP-5926 Rev 4\Calculations

This spreadsheet uses the input data to calculate the gas generation rates, then calculates the flammability and time to LFL for a given ventilation rate.

A new Excel spreadsheet "RPP-CALC-29700 Rev 0 Calculations.xls" was created by copying the necessary worksheets from the master spreadsheet RPP-5926-8050-R4-LFL-CAL-T2-122004.xls (above) to calculate the time to LFL for the 242-A Evaporator case study. This new spreadsheet was verified in compliance with TFC-ENG-DESIGN-C-32, *Spreadsheet Development and Verification*, and is documented in spreadsheet verification form SVF-1165.

Spreadsheet owner: T. A. Hu

Spreadsheet name: RPP-CALC-29700 Rev 0 Calculations.xls

Spreadsheet location: *Hanford\Data\Sitedata* \FlamGas\RPP-5926 Rev 5\Evaporator 242-A\Final Document

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8.0 RESULTS

Model calculations on flammability level, time to reach 25% and 100% of the LFL, and minimum vent rate to keep below 25% and 100% of the LFL are performed on the evaporation process of the 242-A Evaporator using the current 28 DST liquid wastes under various temperature, SpG, and ammonia conditions. The flammability analysis has also been performed on the blended waste mixture of tanks 241-AP-104 and 241-AW-102 in the evaporator campaigns 07-01 and 07-02, the shutdown mode and the start-up mode of the operations. In addition, the flammability evaluation of the usage of AFA in the waste feed, which will increase the TOC concentration and thus increase the gas generation rate, has been performed. The results are given in the following sections.

8.1 FLAMMABILITY LEVEL ON C-A-1 UNDER AMBIENT PRESSURE

The flammability analysis modeled the cases where the concentrated waste sits on the C-A-1 vessel at the target SpG and operating temperature condition while the headspace pressure is ambient pressure of 1 atm under either barometric breathing or no ventilation. The flammable gas generated from the waste accumulates in the headspace, thus the steady-state flammability under barometric breathing and time to reach 25% and 100% of the LFL can be calculated. As mentioned in Section 4.0, the flammability analysis on C-A-1 has included the headspace of C-A-1 plus the gaseous effluent pathway of 42-in. pipeline and the vapor pathway in the primary condenser. In the calculations, the waste-filled faction is 0.69 for the HGR calculations and is 0.62 for the flammability calculation to cover the extended headspace. The results for the following cases are given in Appendix B.

Case 1:	Raw waste condition.
Cases 2-5 and 11:	With SpG of 1.5 and 30% feed ammonia at temperature of 120, 130, 140, 150, and 155 °F.
Cases 9-10:	With SpG of 1.55 and 30% feed ammonia at temperature of 150 and 155 °F.
Cases 8 and 12-13:	With SpG of 1.6 and 30% feed ammonia at waste temperature of 150, 155 and 160 °F.
Cases 14:	With SpG of 1.7, and 30% feed ammonia at waste temperature of 155 °F
Cases 6-7:	With SpG of 1.5 and 1.6, and 100% feed ammonia at waste temperature of 150 °F

The results tables in Appendix B list the required HGR, ammonia transport properties, steady-state flammability of ammonia, the time to reach 25% and 100% of the LFL under both barometric breathing and zero ventilation conditions, and the minimum vent rate to keep below

25% of the LFL. A summary on the time to reach 25% of the LFL for the top five tanks is given in Table 8-1.

Table 8-1. Time to 25% of the Lower Flammability Limit for the Top Five Tanks.

Tanks			241-AN-102	241-AN-107	241-AP-103	241-AP-106	241-SY-103
Conditions	**Cases**	**SpG**	**Time to 25% of the lower flammability limit (days)**				
150 °F and 30% Feed NH_3	5	1.50	1.7	3.3	4.1	4.8	4.7
	10	1.55	1.5	2.9	3.6	4.3	4.0
	8	1.60	1.3	2.6	3.2	3.8	3.4
155 °F and 30% Feed NH_3	11	1.50	1.3	2.6	3.2	3.7	3.7
	9	1.55	1.2	2.3	2.8	3.3	3.1
	12	1.60	1.0	2.0	2.5	2.9	2.6
	14	1.70	0.8	1.6	1.9	2.3	2.0

A sensitivity plot of Table 8-1 is given in Figure 8-1. It is plot of time to 25% of the LFL versus the SpG. Each line represents a tank at certain temperature with very similar slope. The bottom two lines are DST 241-AN-102 at 155 and 150 °F, respectively, which gives the shortest time to 25% of the LFL ranging 1.0 to 1.7 days. The next lowest line set is DST 241-AN-107 with tank DST 241-AP-103 at 155 °F in between. The highest line set is for DST 241-AP-106 while DSTs 241-SY-103 and 241-AP-103 are in between. Note that for each set, the higher temperature is in the lower side which has shorter time to 25% of the LFL. DST 241-SY-103 has the largest slope at 150 °F, and it has nonlinear behavior at 155 °F. This is because the ammonia has a larger contribution to the total flammability while the linear behavior on SpG is the characteristic of hydrogen generation.

In addition, to support the analysis in HNF-SD-WM-FHA-024, *Fire Hazards Analysis for the Evaporator Facility (242-A)*, an estimate of how much time it will take for the C-A-1 to reach 750% of the LFL (which is equivalent to 30 volume percent of hydrogen) is performed. Using the case 12 condition (temperature at 155 °F and SpG of 1.6) with the tank waste of DST 241-AN-102, the time to reach 750% of the LFL is 31.9 days.

Figure 8-1. Time to 25% of the Lower Flammability Limit Versus Target Slurry SpG.

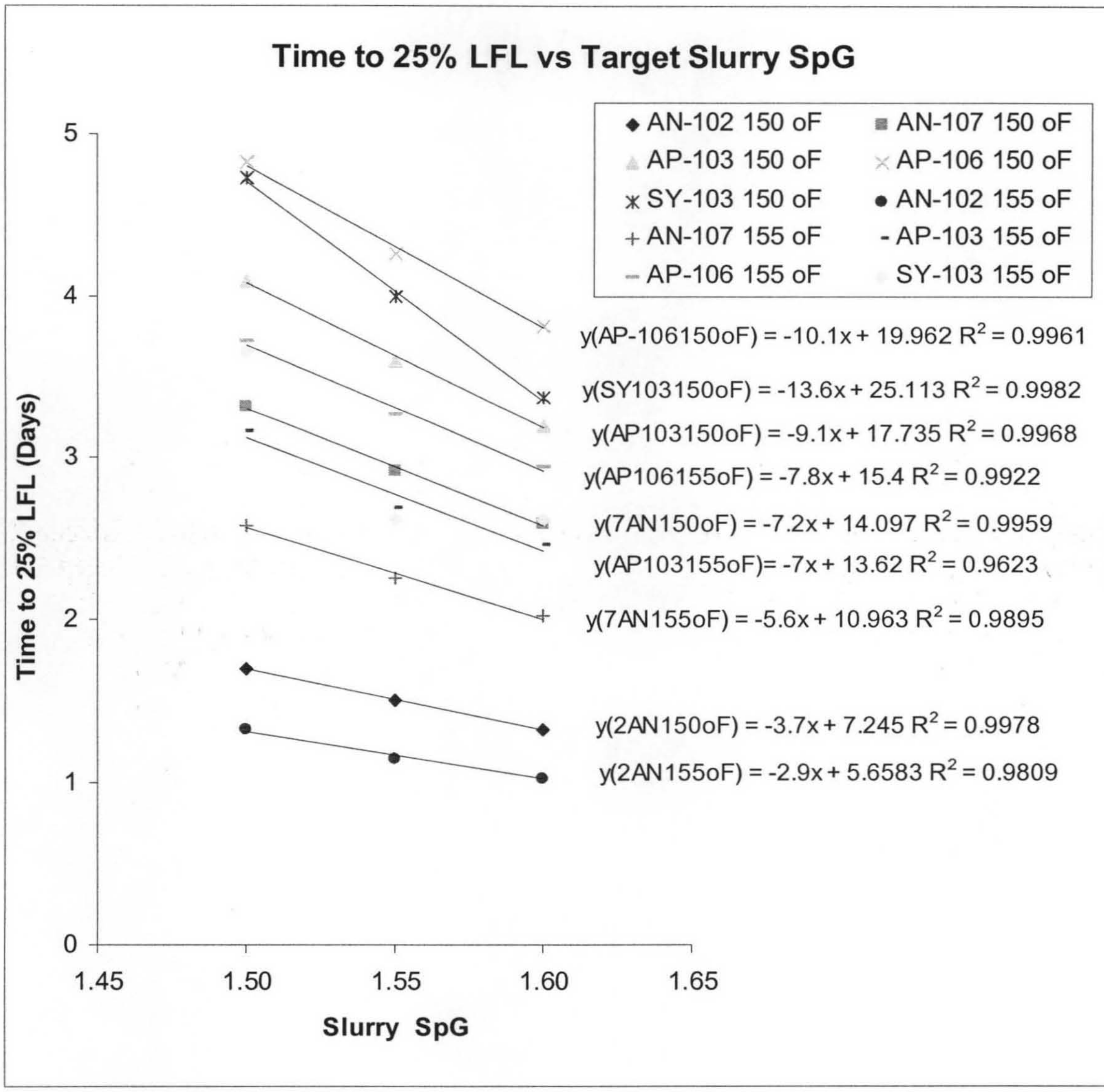
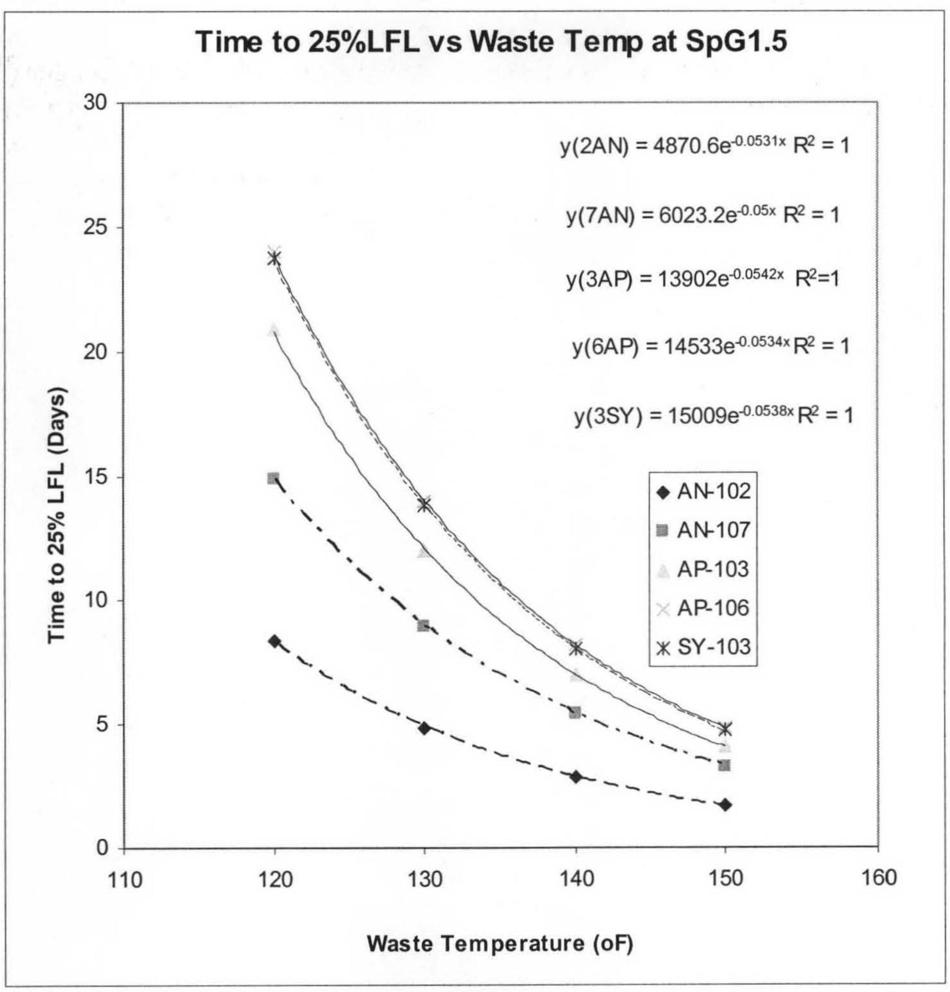


Table 8-2 summarizes the time to 25% of the LFL as function of temperature at SpG of 1.5 and 30% of the feed ammonia condition for the top five tanks. For each tank, apparently the higher the temperature, the shorter time to 25% of the LFL. Figure 8-2 plots the behavior of time to 25% of the LFL as function of temperature.

Table 8-2. Summary of Time to 25% of the Lower Flammability Limit as Function of Temperature.

Waste condition	Cases	Temp (°F)	Time to reach 25% of the lower flammability limit (days)				
			241-AN-102	241-AN-107	241-AP-103	241-AP-106	241-SY-103
SpG 1.5 and 30% NH_3 left	Case 2	120	8.4	14.9	21.0	24.1	23.9
	Case 3	130	4.9	9.0	12.1	14.0	13.9
	Case 4	140	2.9	5.5	7.0	8.2	8.1
	Case 5	150	1.7	3.3	4.1	4.8	4.7

Figure 8-2. Time to 25% of the Lower Flammability Limit Versus Temperature.



As shown in Figure 8-2, the time to 25% of the LFL decreases exponentially as function of temperature. It is because the HGR, and thus the flammability, is increased exponentially as function of temperature; therefore, the time to reach 25% of the LFL becomes shorter as the temperature increases.

In addition to the above analyses using the 28 DSTs waste inventory as the available source waste spectrum, the flammability analyses performed for 242-A Evaporator campaigns 07-01 and 07-02 are presented in Appendix D. Campaigns 07-01 and 07-02 blended the waste of DSTs 241-AP-104 and 241-AW-102 together for evaporation and the analysis provides the case studies on a mixture of DST wastes. The resulting time to 25% of LFL at zero ventilation rate for different waste mixtures at various SpG and waste temperatures are summarized in Table 8-3.

Table 8-3. Summary of the Time to 25% of Lower Flammability Limit Under Zero Vent for Evaporator Campaign 07-01 and 07-02.

Cases of time to 25% of the LFL (days)	SpG 1.6, 160 °F	SpG 1.7, 155 °F	SpG 1.6, 155 °F	SpG 1.6, 150 °F	SpG 1.55, 155 °F	SpG 1.55, 150 °F	SpG 1.50, 155 °F	SpG 1.50, 150 °F
Raw 241-AP-104	2.33	2.29	3.04	3.94	3.49	4.53	4.01	5.20
2AW-0.25/4AP-0.75	2.12	2.11	2.76	3.58	3.16	4.10	3.62	4.70
2AW-0.45/4AP-0.55	2.03	2.05	2.64	3.43	3.01	3.90	3.44	4.47
2AW-0.5/4AP-0.5	2.01	2.04	2.62	3.40	2.98	3.87	3.41	4.43
2AW-1.0/4AP-0.0	2.08	2.21	2.69	3.0	3.01	3.91	3.37	4.41
Raw 241-AW-102	2.06	2.18	2.67	3.47	2.99	3.88	3.38	4.39

Note:

The mixed waste case models different percentage of waste volume between 2AW and 4AP feed to evaporator. The 241-AW-102 waste in the mixture waste has been concentrated from the SpG of 1.07 to 1.28 to match the SpG of 241-AP-104 waste for better mixing. Thus the SpG of mixture waste starts at 1.28 and is concentrated to different target SpG at various temperatures. The cases of raw waste 241-AP-104 (at SpG 1.28) and 241-AW-102 (at SpG 1.07) are also included for comparison.

LFL = lower flammability limit.

The issue of adding the AFA has been intensively investigated by the Savannah River National Laboratory (WSRC-TR-2005-00281, *Hydrogen Generation Rate Scoping Study of Dow Corning Antifoam Agent*) for the Waste Treatment and Immobilization Plant at the Hanford Site. The investigation was to determine if the organic components of the AFAs produce hydrogen in the same manner as the native organic species in Hanford tank waste. The test results from this study indicate that the model calculated HGR bounds the measured HGRs from antifoam-containing simulants if the antifoam organic components are treated the same as the native organics.

During the evaporation process, starting when water is in the vessel, an AFA, DOW 1520, is injected. At the evaporator, it is diluted with water and then fed into the process at 0.01 to 0.1 gal/min.

The intention of the following analysis is to examine the effect of the AFA on the HGRs and the time to reach 25% of the LFL. It is assumed, in the analysis, that the pure liquid AFA DOW 1520 has density of 1 g/mL and 13 wt% of TOC (see Appendix F). Thus, the TOC concentration of pure liquid AFA is 0.13 g/mL, whereas the actual injected AFA liquid is diluted at least 1:1 with water. For given diluted AFA liquid with TOC concentration of 0.065 g/mL and injection rate of 0.1 gal/min to the feed stream, the TOC concentration of the feed can be recalculated as follows.

$$[TOC]^{new}_{feed} = \frac{R_{feed} \times [TOC]^{old}_{feed} + R_{AFA}[TOC]_{AFA}}{R_{feed} + R_{AFA}} \tag{8-1}$$

where:

R_{feed}	=	the flow rate of feed stream (conservatively use 70 gal/min, from Table 2-2, HNF-14755)
R_{AFA}	=	the flow rate of AFA injection (use 0.1 gal/min)

Considering an AFA injection rate of 0.1 gal/min, the TOC concentration, HGRs, and time to reach 25% of the LFL are calculated for the waste of 28 DSTs at a reasonably conservative, targeted evaporation condition of 150 °F, 1.6 SpG with 30% of feed ammonia remaining. The input data for 28 DSTs are the same as listed in Appendix A except the TOC concentrations are modified with Equation 8-1. The times to 25% of the LFL are given in Table 8-4.

In addition, the AFA might be used when the waste feed is stopped. The model calculations of the time to reach 25% of the LFL are also performed for the condition of mixing one, two, and three 55-gal drums (i.e., 55 gal, 110 gal, and 165 gal) of AFA with 26,000 gal of raw feed waste in the C-A-1 evaporator vessel. The calculation results are listed in Table 8-4. One drum (55 gal) of AFA is considered reasonably conservative based on the maximum injection rate of 0.1 gal/min, experience with the quantity of AFA used during past and recent 242-A Evaporator campaigns, and the standard practice of shutting off the AFA when in recirculation (see Appendix G). Three drums (165 gal) of AFA in the C-A-1 evaporator vessel provides additional margin and is considered bounding. In addition, the antifoam tank TK-E-102 used to mix and supply antifoam solutions to the C-A-1 evaporator vessel only has a 100 gal capacity and, therefore, holds less than one 55-gal drum of AFA at a 1:1 dilution with water. Thus, operator action is required to add more than one drum.

For comparison, the TOC of raw feed liquid waste and the time to 25% of the LFL for the cases without AFA are listed in Table 8-4. Also, the percentage increase in TOC after addition of AFA and the ratio of the time to 25% of the LFL with and without AFA are given in Table 8-4. In general, the times to 25% of the LFL are shorter for the condition with one drum (55 gal) of AFA added than for the condition with AFA fed at 0.1 gal/min and for the condition of more drums of AFA due to the larger TOC increase. The addition of AFA may significantly affect the calculated time to 25% of the LFL. For example, the time to 25% of the LFL with zero ventilation for tank 241-AZ-102 is decreased from 3.6 to 3.2 days (an 11% decrease) by the addition of one drum (55 gal) of AFA and from 3.6 to 2.6 days (a 28% decrease) by the addition of three drums (165 gal) of AFA.

Based on these results, the addition of three 55-gal drums (165 gal) of AFA to the C-A-1 evaporator vessel should be included in the methodology of flammability analysis for the evaporator as required by TSR AC 5.6.1.9 (HNF-15279, *Technical Safety Requirements for the 242-A Evaporator*).

Table 8-4. Total Organic Carbon and Time to 25% of the Lower Flammability Limit Calculations With and Without Antifoam Agent. (2 sheets)

Tank Waste at SpG 1.6, temp. 150 °F and 30% feed NH_3	Without AFA		0.1 gal/min AFA Feed			1 Drum (55 gal) AFA			2 Drum (110 gal) AFA			3 Drum (165 gal) AFA		
	Feed Liquid TOC (μg/ml)	Time to 25% LFL no vent (days)	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA
241-AN-101	5.11E+03	5.7	5.6	1.7%	0.98	5.4	5.4%	0.95	5.2	10.7%	0.90	4.9	16.0%	0.86
241-AN-102	2.41E+04	1.3	1.3	0.2%	0.99	1.3	1.0%	0.99	1.3	1.9%	0.98	1.3	2.9%	0.97
241-AN-103	3.05E+03	8.8	8.6	2.9%	0.97	8.1	9.1%	0.92	7.5	18.2%	0.85	7.0	27.3%	0.79
241-AN-104	3.14E+03	6.0	5.8	2.8%	0.97	5.5	8.9%	0.92	5.1	17.7%	0.85	4.7	26.5%	0.79
241-AN-105	2.76E+03	7.6	7.3	3.2%	0.97	6.9	10.1%	0.91	6.3	20.2%	0.83	5.8	30.2%	0.77
241-AN-106	2.10E+03	4.1	3.9	4.3%	0.96	3.6	13.4%	0.88	3.2	26.7%	0.79	2.9	40.0%	0.71
241-AN-107	3.25E+04	2.6	2.6	0.1%	1.00	2.6	0.7%	0.99	2.6	1.3%	0.98	2.5	2.0%	0.98
241-AP-101	1.90E+03	14.0	13.3	4.8%	0.95	12.2	14.8%	0.87	10.8	29.6%	0.77	9.7	44.3%	0.69
241-AP-102	3.01E+03	7.0	6.8	3.0%	0.97	6.4	9.3%	0.91	5.9	18.5%	0.84	5.5	27.7%	0.78
241-AP-103	7.27E+03	3.2	3.1	1.1%	0.99	3.1	3.7%	0.97	3.0	7.4%	0.93	2.9	11.1%	0.90
241-AP-104	4.15E+03	4.4	4.3	2.1%	0.98	4.1	6.6%	0.94	3.9	13.3%	0.88	3.6	19.9%	0.83
241-AP-105	1.49E+03	9.6	9.1	6.1%	0.94	8.1	18.9%	0.84	7.0	37.7%	0.73	6.2	56.4%	0.64
241-AP-106	3.46E+03	3.8	3.7	2.6%	0.97	3.5	8.0%	0.92	3.3	16.0%	0.86	3.1	23.9%	0.81
241-AP-107	2.33E+03	7.5	7.3	3.9%	0.96	6.7	12.0%	0.89	6.1	24.0%	0.81	5.6	35.9%	0.73
241-AP-108	4.18E+03	6.2	6.1	2.1%	0.98	5.8	6.6%	0.94	5.5	13.2%	0.88	5.2	19.7%	0.84
241-AW-101	2.61E+03	11.4	11.0	3.4%	0.97	10.3	10.7%	0.90	9.4	21.4%	0.82	8.7	32.0%	0.76
241-AW-102	2.25E+03	8.1	7.8	4.0%	0.96	7.2	12.5%	0.89	6.5	24.9%	0.80	5.9	37.2%	0.73
241-AW-103	2.06E+03	6.1	5.9	4.4%	0.96	5.4	13.6%	0.88	4.8	27.2%	0.79	4.4	40.7%	0.71
241-AW-104	4.32E+03	4.8	4.8	2.0%	0.98	4.6	6.4%	0.94	4.3	12.8%	0.89	4.1	19.1%	0.84
241-AW-105	4.08E+02	32.5	26.7	22.8%	0.81	19.5	69.7%	0.58	13.9	139.1%	0.41	10.8	208.2%	0.32
241-AW-106	1.77E+03	9.9	9.4	5.2%	0.95	8.6	15.9%	0.86	7.6	31.8%	0.76	6.8	47.6%	0.68
241-AY-101	1.35E+03	12.8	12.0	6.8%	0.94	10.6	20.9%	0.82	9.1	41.7%	0.70	7.9	62.4%	0.61
241-AY-102	8.16E+02	32.7	29.5	11.3%	0.89	24.5	34.7%	0.73	19.6	69.3%	0.58	16.4	103.8%	0.48

Table 8-4. Total Organic Carbon and Time to 25% of the Lower Flammability Limit Calculations With and Without Antifoam Agent. (2 sheets)

Tank Waste at SpG 1.6, temp. 150 °F and 30% feed NH_3	Without AFA		0.1 gal/min AFA Feed			1 Drum (55 gal) AFA			2 Drum (110 gal) AFA			3 Drum (165 gal) AFA		
	Feed Liquid TOC (μg/ml)	Time to 25% LFL no vent (days)	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA	Time to 25% LFL no vent (days)	TOC increase after addition of AFA (%)	TTLFL (25%) with/wo AFA
241-AZ-101	5.14E+02	20.7	18.3	18.1%	0.88	14.7	55.3%	0.70	11.4	110.4%	0.54	9.4	165.3%	0.44
241-AZ-102	1.99E+03	3.6	3.5	4.6%	0.96	3.2	14.1%	0.88	2.9	28.1%	0.79	2.6	42.1%	0.71
241-SY-101	2.30E+03	9.6	9.2	3.9%	0.96	8.6	12.2%	0.89	7.7	24.3%	0.80	7.1	36.3%	0.73
241-SY-102	1.24E+03	17.3	16.1	7.4%	0.93	14.1	22.7%	0.81	12.0	45.3%	0.68	10.4	67.9%	0.59
241-SY-103	6.22E+03	3.4	3.3	1.4%	0.99	3.2	4.4%	0.96	3.1	8.7%	0.92	3.0	13.0%	0.89

Notes:

AFA = antifoaming agent
LFL = lower flammability limit.
TOC = total organic carbon
TTLFL = time to lower flammability limit.

The flammability analyses for the shutdown mode (with 10,000 gal in the C-A-1 evaporator vessel) and the startup operation (with 26,000 gal in the C-A-1 evaporator vessel) of the evaporator process prior to liquid waste feed are presented in Appendix E. The shutdown mode and the startup operation do not involve slurry feed; only water, AFA, process condensate, and inhibited water (i.e., water treated with hydroxide and/or nitrite used for corrosion control). In the analyses, slightly contaminated process condensate collected in tank TK-C-100 is used as the bounding case. The shutdown and startup analyses both assumed the addition of three 55-gal drum of AFA. Table 8-5 lists the time to 25% of the LFL at zero ventilation for both shutdown and startup cases.

Table 8-5. Summary of Time to 25% of the Lower Flammability Limit for the Shutdown and Startup Modes.

Tanks	**Filled waste fraction f**	**Time to Reach 25% LFL at BB vent (days)**	**Time to Reach 100% LFL at BB vent (days)**	**Time to Reach 25% LFL at Zero vent (days)**	**Time to Reach 100% LFL at Zero vent (days)**
Shutdown mode	0.24	not occur	not occur	> 2000	> 2000
Start-up mode	0.62	not occur	not occur	1079	1755

Notes:
BB = barometric breathing.
LFL = lower flammability limit.

8.2 FLAMMABILITY LEVEL ON TK-C-100 UNDER AMBIENT PRESSURE

Tank TK-C-100 collects the liquid condensation from the primary condenser, inter-condenser, and after-condenser and operates at ambient temperature (85 °F) and pressure (1 atm). The condensation contains mainly contaminated water with dissolved ammonia. The concentrations of radionuclides and other chemicals are small and can be ignored in this analysis. Thus, the flammability analysis includes only hydrogen generation from corrosion and the ammonia concentration at equilibrium between the liquid and vapor phases. Results are calculated at various (10% increments) up to the level of overflow (about 85% full).

Table 8-6 lists the ammonia concentrations from analysis of samples from condensate tank TK-C-100. Two ammonia liquid concentrations of 0.29 and 0.77 g/L (from March 22, 2005, and September, 3, 2003, respectively) were chosen for use in the flammability analysis.

Table 8-6. Measured Ammonia Concentration in Condensate Tank TK-C-100.

Sample Date	Ammonia sample concentration* (μg/mL)
04/25/00	118
04/26/00	108
05/02/00	145
03/18/01	58
03/21/01	65
09/02/03	752
09/03/03	769
03/18/04	57
03/24/04	84
03/22/05	289
03/24/05	204

Note:
*RPP-21926, 2004, *242-A Evaporator Vapor Emissions Estimate Using Environmental Simulation Program (ESP) Model*, Appendix B, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

The NH_4^+ concentration in the stream that exits the condensate tank is 2.3 g/L according to the process flow data in HNF-14755, Table 2B. This indicates that the ammonia concentrations in Table 8-6 may not be bounding. Therefore, at the request of a 242-A Evaporator process engineer, flammability analyses were performed for condensate ammonia concentrations of 3 and 6.8 g/L. Details of the calculation results are given in Appendix C. Table 8-7 summarizes the time to 25% of the LFL under both barometric breathing and zero ventilation conditions.

As shown in Table 8-7, none of the conditions will exceed the 25% of the LFL under the barometric breathing condition. Under zero ventilation, the shortest time to reach 25% of the LFL is 432 days when the waste is 85% full at the ammonia concentration of 6.8 g/L.

Table 8-7. Steady-State Flammability and Time to Lower Flammability Limit for TK-C-100 of 242-A Evaporator. (2 sheets)

Tanks	Filled fraction	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Steady-state NH_3 LFL (%)	Steady-state H_2 LFL (%)	Steady-state CH_4 LFL (%)	Steady-state LFL at BB (%)
05-01 (2005) campaign (RPP-RPT-27963) with NH_3 concentration of 0.289 g/L at temperature of 85 °F water	0.10	not occur	not occur	2,000	2,000	0.2%	0.5%	0.00%	0.8%
	0.20	not occur	not occur	2,000	2,000	0.2%	0.8%	0.00%	1.0%
	0.30	not occur	not occur	2,000	2,000	0.2%	1.1%	0.00%	1.3%
	0.40	not occur	not occur	2,000	2,000	0.2%	1.5%	0.00%	1.7%
	0.50	not occur	not occur	2,000	2,000	0.2%	2.1%	0.00%	2.3%
	0.60	not occur	not occur	1,899	2,000	0.2%	2.9%	0.00%	3.2%
	0.70	not occur	not occur	1,270	2,000	0.2%	4.4%	0.00%	4.6%
	0.80	not occur	not occur	764	2,000	0.2%	7.2%	0.00%	7.5%
	0.85	not occur	not occur	547	2,000	0.2%	10.1%	0.00%	10.3%
9/3/2003 sample of NH_3 concentration of 0.769 g/L at temperature of 85 °F water	0.10	not occur	not occur	2,000	2,000	0.6%	0.5%	0.00%	1.1%
	0.20	not occur	not occur	2,000	2,000	0.6%	0.8%	0.00%	1.4%
	0.30	not occur	not occur	2,000	2,000	0.6%	1.1%	0.00%	1.7%
	0.40	not occur	not occur	2,000	2,000	0.6%	1.5%	0.00%	2.1%
	0.50	not occur	not occur	2,000	2,000	0.6%	2.1%	0.00%	2.7%
	0.60	not occur	not occur	1,870	2,000	0.6%	2.9%	0.00%	3.5%
	0.70	not occur	not occur	1,251	2,000	0.6%	4.4%	0.00%	5.0%
	0.80	not occur	not occur	752	2,000	0.6%	7.2%	0.00%	7.8%
	0.85	not occur	not occur	538	2,000	0.6%	10.1%	0.00%	10.7%
Case of NH_3 concentration of 3 g/L at temperature of 85 °F water	0.10	not occur	not occur	2,000	2,000	2.4%	0.5%	0.00%	2.9%
	0.20	not occur	not occur	2,000	2,000	2.4%	0.8%	0.00%	3.2%
	0.30	not occur	not occur	2,000	2,000	2.4%	1.1%	0.00%	3.5%
	0.40	not occur	not occur	2,000	2,000	2.4%	1.5%	0.00%	3.9%
	0.50	not occur	not occur	2,000	2,000	2.4%	2.1%	0.00%	4.4%
	0.60	not occur	not occur	1,733	2,000	2.4%	2.9%	0.00%	5.3%
	0.70	not occur	not occur	1,160	2,000	2.4%	4.4%	0.00%	6.7%
	0.80	not occur	not occur	698	2,000	2.4%	7.2%	0.00%	9.6%
	0.85	not occur	not occur	499	2,000	2.4%	10.1%	0.00%	12.5%

Table 8-7. Steady-State Flammability and Time to Lower Flammability Limit for TK-C-100 of 242-A Evaporator. (2 sheets)

Tanks	Filled fraction	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Steady-state NH_3 LFL (%)	Steady-state H_2 LFL (%)	Steady-state CH_4 LFL (%)	Steady-state LFL at BB (%)
Case of NH_3 concentration of 6.8 g/L at temperature of 85 °F water	0.10	not occur	not occur	2,000	2,000	5.4%	0.5%	0.00%	5.9%
	0.20	not occur	not occur	2,000	2,000	5.4%	0.8%	0.00%	6.2%
	0.30	not occur	not occur	2,000	2,000	5.4%	1.1%	0.00%	6.5%
	0.40	not occur	not occur	2,000	2,000	5.4%	1.5%	0.00%	6.9%
	0.50	not occur	not occur	2,000	2,000	5.4%	2.1%	0.00%	7.5%
	0.60	not occur	not occur	1,501	2,000	5.4%	2.9%	0.00%	8.3%
	0.70	not occur	not occur	1,004	2,000	5.4%	4.4%	0.00%	9.7%
	0.80	not occur	not occur	605	2,000	5.4%	7.2%	0.00%	12.6%
	0.85	not occur	not occur	432	2,000	5.4%	10.1%	0.00%	15.5%

Notes:

RPP-RPT-27963, 2005, *242-A Evaporator Campaign 05-01 Vapor Emissions Evaluation*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

BB = barometric breathing.
LFL = lower flammability limit.

8.3 FLAMMABILITY LEVEL ON GASEOUS EFFLUENT AFTER PRIMARY CONDENSER UNDER VACUUM

During the normal evaporation process, the evaporator runs under vacuum and high temperature. For the headspace of C-A-1, during the normal evaporation process, the majority of the vapor is water with some ammonia, hydrogen, and methane; there is very limited air and thus no flammable gas concern. This is also true for the 42-in. pipeline between the C-A-1 vessel and primary condenser. Since air flow is introduced to and joins with the exit vapors from the primary condenser, a flammability analysis for the gaseous effluent after the primary condenser was conducted. A bounding case of waste temperature 155 °F and SpG of 1.6 is evaluated for all 28 DSTs on the C-A-1 vessel under vacuum condition using Equations 6-15 to 6-21. The parameters used in the calculations are summarized in Table 8-8, including the in-leakage air flow (at 1 atm), the feed flow rate, the slurry flow rate, the ammonia fraction of the feed to slurry, the ammonia fraction of the vapor stream from headspace survived after primary condensation.

Table 8-8. Parameters Used in the Flammability Analysis on C-A-1 Under Vacuum Condition.

Parameters	Air[a] (L/min)	Feed[d] (L/min)	Slurry[d] (L/min)	Slurry NH_3frac[b]	Vent NH_3frac[c]	NH_3 (g/mole)	Volume (gallon)	Conversion (liter/gallon)
Values	740	494	265	0.1	0.0857	17.03	26,000	3.7854

Notes:
[a]Air rate from stream 27 (HNF-14755, Table 2B-1).
[b]Ratio of Stream 1 and 2 (HNF-14755, Table 2B-1).
[c]Ratio of Stream 6 and 4 (HNF-14755, Table 2B-1).
[d]HNF-14755, Table 2-2.

HNF-14755, *Documented Safety Analysis for the 242-A Evaporator*, as amended, CH2M HILL Hanford Group, Inc., Richland, Washington.

The results of the flammability analysis on the gaseous effluent after primary condenser are summarized in Table 8-9. A sensitivity check of the total flammability on the ammonia fraction of the vapor stream to the vent is performed using the fraction at 0.1 instead of 0.086 and the results are listed in the last column of Table 8-9. The results show that ammonia is the dominant fraction of total flammability. The highest total flammability is 58% and 67% of the LFL on the NH_3 fraction to vent at 0.086 and 0.1, respectively. Note that the flammability is linearly proportional to ammonia concentration in the feed liquid waste and inversely proportional to the in-leakage air flow. This analysis reviewed 28 DST current liquids using the air flow rate at the 30 torr condition. If the same flow rate was maintained, and the ammonia concentration was increased to 2.4 g/L, the gaseous effluent after the primary condenser would reach 100% of the LFL. Or, if the air flow drops by 46% while processing the current bounding tank liquid at its highest ammonia concentration (1.29 g/L), the gaseous effluent after the primary condenser would reach 100% of the LFL.

Table 8-9. Flammability of the Gaseous Effluent After Primary Condenser with Air In-Leakage. (2 sheets)

Tank ID	Feed liquid NH_3 (μg/ml)	U_{H2} unit rate of hydrogen (mole/min)	U_{CH4} unit rate of methane (mole/min)	Nominal U_{NH3} vapor form C-A-1 to vent at 0.086 (mole/min)	Nominal hydrogen H_2 (%LFL)	Nominal methane CH_4 (%LFL)	Nominal ammonia NH_3 (%LFL)	Nominal total flamm. (%LFL) with NH_3-vent at 0.086	Sensitivity check total flamm. (%LFL) with NH_3-vent at 0.1
241-AN-101	1.68E+02	3.07E-03	3.06E-04	0.396	0.06	0.01	8.19	8.3	9.6
241-AN-102	2.10E+02	1.30E-02	1.30E-03	0.494	0.27	0.03	10.17	10.5	12.1
241-AN-103	3.45E+02	1.84E-03	1.83E-04	0.812	0.04	0.00	16.56	16.6	19.3
241-AN-104	2.46E+02	2.66E-03	2.65E-04	0.579	0.05	0.01	11.89	12.0	13.9
241-AN-105	2.10E+02	2.18E-03	2.17E-04	0.494	0.05	0.00	10.18	10.2	11.9
241-AN-106	2.10E+02	4.28E-03	4.27E-04	0.494	0.09	0.01	10.18	10.3	11.9
241-AN-107	2.10E+02	6.70E-03	6.69E-04	0.494	0.14	0.01	10.18	10.3	12.0
241-AP-101	4.39E+02	1.21E-03	1.20E-04	1.033	0.02	0.00	20.93	21.0	24.3
241-AP-102	4.39E+02	2.34E-03	2.33E-04	1.033	0.05	0.00	20.93	21.0	24.3
241-AP-103	2.50E+02	5.34E-03	5.33E-04	0.588	0.11	0.01	12.08	12.2	14.2
241-AP-104	1.33E+02	4.04E-03	4.03E-04	0.313	0.08	0.01	6.48	6.6	7.6
241-AP-105	3.24E+02	1.61E-03	1.60E-04	0.762	0.03	0.00	15.57	15.6	18.1
241-AP-106	6.75E+01	4.65E-03	4.64E-04	0.159	0.10	0.01	3.31	3.4	4.0
241-AP-107	1.14E+03	2.11E-03	2.10E-04	2.682	0.04	0.00	51.75	51.8	59.7
241-AP-108	9.63E+02	2.54E-03	2.53E-04	2.267	0.05	0.00	44.27	44.3	51.1
241-AW-101	1.00E+01	1.57E-03	1.56E-04	0.024	0.03	0.00	0.49	0.5	0.6
241-AW-102	7.43E+01	2.20E-03	2.19E-04	0.175	0.05	0.00	3.64	3.7	4.3
241-AW-103	5.12E+02	2.42E-03	2.41E-04	1.205	0.05	0.00	24.28	24.3	28.2
241-AW-104	1.69E+02	3.62E-03	3.61E-04	0.398	0.07	0.01	8.21	8.3	9.6
241-AW-105	1.01E+03	5.21E-04	5.09E-05	2.376	0.01	0.00	46.26	46.3	53.4
241-AW-106	3.55E+02	1.70E-03	1.69E-04	0.835	0.03	0.00	17.03	17.1	19.8
241-AY-101	1.13E+02	1.34E-03	1.33E-04	0.266	0.03	0.00	5.52	5.5	6.5

Table 8-9. Flammability of the Gaseous Effluent After Primary Condenser with Air In-Leakage. (2 sheets)

Tank ID	Feed liquid NH_3 (μg/ml)	U_{H2} unit rate of hydrogen (mole/min)	U_{CH4} unit rate of methane (mole/min)	Nominal U_{NH3} vapor form C-A-1 to vent at 0.086 (mole/min)	Nominal hydrogen H_2 (%LFL)	Nominal methane CH_4 (%LFL)	Nominal ammonia NH_3 (%LFL)	Nominal total flamm. (%LFL) with NH_3-vent at 0.086	Sensitivity check total flamm. (%LFL) with NH_3-vent at 0.1
241-AY-102	7.37E+01	5.44E-04	5.32E-05	0.173	0.01	0.00	3.61	3.6	4.2
241-AZ-101	1.25E+02	7.83E-04	7.71E-05	0.294	0.02	0.00	6.10	6.1	7.1
241-AZ-102	4.38E+02	3.91E-03	3.90E-04	1.031	0.08	0.01	20.88	21.0	24.3
241-SY-101	1.04E+03	1.61E-03	1.60E-04	2.456	0.03	0.00	47.71	47.7	55.0
241-SY-102	1.15E+03	9.60E-04	9.49E-05	2.706	0.02	0.00	52.17	52.2	60.1
241-SY-103	1.29E+03	4.09E-03	4.08E-04	3.035	0.08	0.01	57.97	58.1	66.7

Note:
LFL = lower flammability limit.

9.0 CONCLUSIONS

Flammability evaluations of the evaporation process at the 242-A Evaporator were performed. Three facilities under two conditions of ambient pressure and low vacuum were identified: C-A-1 headspace, gaseous effluent after primary condenser, and condensate tank TK-C-100. Detailed flammability analyses using the liquid waste from 28 DSTs (from RPP-5926) were conducted. In addition, the flammability analyses on a waste mixture from DSTs 241-AP-104 and 241-AW-102 from evaporation campaigns 07-1 and 07-02 were performed. The flammability analyses of the shutdown mode and startup operation with water addition were also performed.

For the waste remaining in the C-A-1 evaporator vessel under ambient pressure (upset off-normal process condition or before/after evaporation process), headspace of C-A-1 can reach 25% of the LFL in a little as 1 day for DST 241-AN-102 liquid waste in the case of target slurry SpG of 1.6 and waste temperature of 155 °F assuming 30% of the ammonia remains in the waste under either barometric breathing or the zero ventilation condition. The headspace of C-A-1 includes the extended vapor space of the gaseous effluent pathway, a 42-in. pipeline between C-A-1 and the primary condenser, and the vapor space in the primary condenser. In general, the flammability level is linearly proportional to the targeted slurry SpG and exponentially proportional to operational temperature or waste temperature. For a given ammonia concentration (maximum of 1.3 g/L in the 28 DSTs), and assuming 30% of the feed ammonia remains in the evaporator vessel, hydrogen is still the dominant contributor to the total flammability.

The flammability level calculation of condensate tank TK-C-100 was conducted at various fill fractions in 10% increments up to the level of overflow, which is 85%. The condensate tank collects condensate, which is mainly contaminated water plus soluble ammonia of concern from all three condensers and operates at ambient pressure (1 atm) and ambient temperature (assumed as 85 °F). The analysis considers only the hydrogen generated from corrosion and the ammonia concentration at equilibrium. Four ammonia concentrations up to 6.8 g/L were evaluated. The results show that none of the cases will reach 25% of the LFL under barometric breathing and under zero ventilation the shortest time to reach 25% of the LFL is 432 days when the tank is 85% filled with an ammonia concentration of 6.8 g/L.

During the normal evaporation process, the liquid waste in the C-A-1 evaporator vessel is evaporated under a vacuum (60 to 80 torr) and heated to an operational temperature (140 to 160 °F). Flammability is not a concern in the headspace of C-A-1, the 42-in. connecting pipeline or the vapor space of the primary condenser since the majority of the vapor generated is water with no air. The exit vapor streams after the primary condenser are mixed with in-leakage air flow and forms a mixture of air and flammable gases. Detailed flammability analyses have been conducted on the mixture of air and flammable gases after the primary condenser; the results show that the highest flammability is 58% of the LFL from DST 241-SY-103 liquid waste. Ammonia is the dominant contributor to the total flammability of the vapor stream after the primary condenser under vacuum condition. The total flammability level is linearly proportional to the ammonia concentration of the feed liquid waste and inversely proportional to the air in-leakage flow rate.

10.0 REFERENCES

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APPENDIX A

INPUT DATA FOR HYDROGEN GENERATION RATES AND AMMONIA EQUILIBRIUM CALCULATIONS

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APPENDIX A

INPUT DATA FOR HYDROGEN GENERATION RATES AND AMMONIA EQUILIBRIUM CALCULATIONS

Table A-1a. Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations from Appendix B and C of RPP-5926, Rev. 5.

Supernatant waste	Na in liquid[a] [Na] (μg/mL)	Al in liquid[a] [Al] (μg/mL)	Fe^{+3} in liquid[b] [Fe+3] (μg/mL)	Cr^{+3} in liquid[b] [Cr+3] (μg/mL)	Ni+2 in liquid[b] [Ni+2] (μg/mL)	K+1 in liquid[b] [K+1] (μg/mL)	TOC in liquid[a] [TOC] (μg/mL)	OH^{-1} in liquid[a] [OH] (μg/mL)
241-AN-101	2.14E+05	1.89E+04	6.32E+00	1.21E+02	3.61E+00	2.68E+03	5.11E+03	3.51E+04
241-AN-102	2.07E+05	1.31E+04	4.90E+01	2.97E+02	4.17E+02	2.88E+03	2.41E+04	8.85E+03
241-AN-103	2.70E+05	2.99E+04	3.01E+01	5.66E+02	1.20E+01	1.68E+04	3.05E+03	6.72E+04
241-AN-104	2.58E+05	3.90E+04	3.01E+01	3.36E+02	1.20E+01	6.69E+03	3.14E+03	6.53E+04
241-AN-105	2.47E+05	4.17E+04	2.47E+01	2.22E+02	9.95E+00	6.50E+03	2.76E+03	5.97E+04
241-AN-106	4.49E+04	4.13E+03	1.77E+00	9.91E+01	2.79E+02	5.96E+03	2.10E+03	5.09E+03
241-AN-107	2.08E+05	1.12E+03	1.67E+03	1.72E+02	5.51E+02	1.81E+03	3.25E+04	1.80E+04
241-AP-101	1.29E+05	7.30E+03	2.50E+00	1.43E+02	7.90E+00	3.12E+04	1.90E+03	3.98E+04
241-AP-102	1.94E+05	3.08E+04	3.82E+00	6.19E+02	2.66E+01	1.29E+03	3.01E+03	3.21E+04
241-AP-103	1.78E+05	1.83E+04	3.01E+01	3.72E+02	1.22E+02	1.33E+04	7.27E+03	1.67E+04
241-AP-104	1.28E+05	1.68E+04	1.04E+02	1.37E+03	7.85E+01	2.11E+03	4.15E+03	1.96E+04
241-AP-105	1.34E+05	1.92E+04	3.01E+01	5.13E+02	2.54E+01	1.23E+04	1.49E+03	2.59E+04
241-AP-106	1.03E+05	1.35E+04	1.13E+02	1.57E+03	7.56E+01	3.12E+03	3.46E+03	7.37E+03
241-AP-107	1.22E+05	1.39E+04	1.01E+01	6.55E+02	2.36E+00	1.58E+03	2.33E+03	1.81E+04
241-AP-108	1.99E+05	2.38E+04	1.01E+01	8.21E+02	4.02E+00	2.85E+03	4.18E+03	3.95E+04
241-AW-101	2.33E+05	2.95E+04	1.80E+01	1.12E+02	6.10E+00	4.12E+04	2.61E+03	9.96E+04
241-AW-102	1.16E+05	1.33E+04	6.95E+00	4.81E+02	1.90E+00	1.32E+03	2.25E+03	1.85E+04
241-AW-103	1.62E+05	1.61E+04	5.57E+00	2.53E+01	5.08E+00	1.43E+04	2.06E+03	1.57E+04
241-AW-104	1.70E+05	2.54E+04	1.86E+00	2.20E+00	7.40E-01	1.67E+03	4.32E+03	2.53E+04
241-AW-105	2.26E+04	1.43E+02	4.61E+00	2.12E+00	9.91E-01	1.99E+03	4.08E+02	4.38E+03
241-AW-106	1.44E+05	2.10E+04	2.18E+01	1.47E+03	8.39E+00	5.65E+03	1.77E+03	2.72E+04
241-AY-101	1.16E+05	4.74E+03	1.20E+01	1.05E+02	5.90E+01	7.63E+02	1.35E+03	3.45E+04
241-AY-102	5.69E+04	1.15E+03	1.01E+01	2.91E+01	4.02E+00	3.88E+02	8.16E+02	7.74E+03
241-AZ-101	1.12E+05	6.10E+03	2.24E+01	7.23E+02	8.02E+00	4.76E+03	5.14E+02	1.15E+04
241-AZ-102	6.15E+04	3.41E+02	1.00E+00	7.37E+02	1.75E+00	3.20E+03	1.99E+03	2.45E+03
241-SY-101	1.37E+05	9.45E+03	3.97E+02	5.18E+03	2.02E+02	4.14E+03	2.30E+03	3.74E+04
241-SY-102	1.22E+05	8.41E+03	1.41E+01	2.41E+02	5.04E+01	1.53E+03	1.24E+03	9.64E+03
241-SY-103	2.15E+05	3.76E+04	2.10E+01	3.30E+01	4.90E+01	3.91E+03	6.22E+03	2.99E+04

Notes:

[a]Input data were taken from Appendix B (hydrogen generation rate input data), which was from the Best-Basis Inventory data download on September 27, 2005.

[b]Input data were taken from Appendix C (ammonia input data), which was prepared in 2001.

RPP-5926, 2005, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, Rev. 5, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table A-1b. Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations from Appendix B and C of RPP-5926, Rev. 5.

Supernatant waste	NO_2 in liquid[a] [NO_2] (μg/mL)	NO_3 in liquid[a] [NO_3] (μg/mL)	CO_3^{-2} in liquid[b] [CO_3^{-2}] (μg/mL)	PO_4^{-3} in liquid[b] [PO_4^{-3}] (μg/mL)	SO_4^{-2} in liquid[b] [SO_4^{-2}] (μg/mL)	F^{-1} in liquid[b] [F^{-1}] (μg/mL)	Cl^{-1} in liquid[b] [Cl^{-1}] (μg/mL)
241-AN-101	1.16E+05	1.62E+05	9.65E+03	1.59E+03	1.36E+03	2.89E+02	2.33E+03
241-AN-102	8.71E+04	2.09E+05	7.00E+04	5.52E+03	1.53E+04	1.91E+03	4.11E+03
241-AN-103	1.30E+05	1.29E+05	5.80E+03	1.65E+03	1.45E+03	6.60E+02	9.76E+03
241-AN-104	1.19E+05	1.89E+05	1.07E+04	2.71E+03	3.54E+03	8.19E+01	8.09E+03
241-AN-105	1.19E+05	1.56E+05	1.18E+04	1.22E+03	2.85E+03	3.06E+02	9.90E+03
241-AN-106	2.01E+04	2.53E+04	2.18E+04	2.02E+03	5.50E+03	5.11E+03	9.60E+02
241-AN-107	6.67E+04	2.09E+05	7.55E+04	2.94E+03	8.98E+03	4.18E+03	2.02E+03
241-AP-101	4.08E+04	1.18E+05	3.23E+04	1.02E+03	4.03E+03	2.90E+03	1.98E+03
241-AP-102	9.82E+04	1.67E+05	2.66E+04	1.16E+04	4.52E+03	1.68E+02	2.73E+03
241-AP-103	8.04E+04	1.49E+05	7.55E+04	3.46E+03	4.50E+03	2.09E+03	2.82E+03
241-AP-104	6.39E+04	1.01E+05	1.93E+04	3.86E+03	3.84E+03	4.15E+02	5.49E+03
241-AP-105	4.73E+04	1.06E+05	1.12E+05	3.16E+03	6.78E+03	4.74E+03	5.45E+03
241-AP-106	4.14E+04	7.07E+04	1.88E+04	2.76E+03	3.20E+03	6.71E+02	4.92E+03
241-AP-107	5.14E+04	1.12E+05	4.55E+03	4.84E+03	2.41E+03	7.22E+02	2.29E+03
241-AP-108	8.02E+04	1.76E+05	1.27E+04	3.40E+03	2.72E+03	9.70E+02	2.86E+03
241-AW-101	1.05E+05	1.71E+05	9.20E+03	9.96E+02	1.26E+03	9.62E+02	7.30E+03
241-AW-102	4.87E+04	1.06E+05	2.31E+03	6.22E+02	1.72E+03	5.42E+02	1.68E+03
241-AW-103	4.30E+04	1.31E+05	4.70E+03	5.92E+01	6.72E+02	1.68E+04	1.38E+02
241-AW-104	7.45E+04	1.12E+05	7.25E+03	2.93E+02	6.54E+02	1.32E+02	2.39E+02
241-AW-105	2.55E+03	2.46E+04	1.62E+03	1.85E+02	3.01E+02	4.81E+02	2.45E+02
241-AW-106	5.49E+04	1.14E+05	2.84E+04	1.47E+03	5.14E+03	1.23E+03	5.17E+03
241-AY-101	3.35E+04	4.65E+03	3.44E+04	1.15E+03	5.87E+03	1.74E+02	6.36E+02
241-AY-102	2.99E+04	3.91E+02	4.87E+04	3.01E+03	2.32E+03	1.72E+02	1.60E+02
241-AZ-101	6.20E+04	5.32E+04	3.42E+04	1.34E+03	1.50E+04	1.75E+03	1.51E+02
241-AZ-102	4.07E+04	8.23E+03	3.50E+04	4.97E+02	1.86E+04	1.14E+03	7.66E+01
241-SY-101	4.14E+04	1.03E+05	3.44E+04	4.94E+03	4.19E+03	5.50E+02	1.11E+04
241-SY-102	2.45E+04	1.65E+05	1.31E+04	3.48E+03	2.91E+03	1.51E+02	4.64E+03
241-SY-103	1.52E+05	1.68E+05	3.44E+04	3.12E+03	4.08E+03	3.51E+02	1.16E+04

Notes:

[a]Input data were taken from Appendix B (hydrogen generation rate input data), which was from the Best-Basis Inventory data download on September 27, 2005.

[b]Input data were taken from Appendix C (ammonia input data), which was prepared in 2001.

RPP-5926, 2005, Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste, Rev. 5, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table A-1c. Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations from Appendix B and C of RPP-5926, Rev. 5.

Supernatant waste	^{90}Sr in waste[a] [Sr] (μCi/g)	^{241}Am in waste[a] [Am241] (μCi/g)	^{240}Pu in waste[a] [Pu240] (μCi/g)	^{239}Pu in waste[a] [Pu240] (μCi/g)	^{238}Pu in waste[a] [Pu238] (μCi/g)	^{137}Cs in waste[a] [Cs] (μCi/g)	$(NH_3)_{ss}$ in dome[b] (ppm)	Liquid NH_3[b] (μg/mL)
241-AN-101	1.27E+00	6.57E-04	1.03E-05	6.21E-05	1.54E-06	1.98E+02	1.13E+01	1.68E+02
241-AN-102	5.60E+01	1.15E-01	8.77E-04	3.37E-03	2.45E-04	2.78E+02	3.00E+02	2.10E+02
241-AN-103	1.19E-02	4.11E-03	4.47E-05	1.72E-04	1.25E-05	4.25E+02	6.65E+00	3.45E+02
241-AN-104	5.84E-02	2.51E-04	1.34E-05	5.16E-05	3.73E-06	3.51E+02	2.10E+01	2.46E+02
241-AN-105	2.44E-02	1.01E-02	1.10E-04	4.24E-04	3.07E-05	2.06E+02	1.51E+01	2.10E+02
241-AN-106	5.72E-01	4.18E-04	4.72E-04	3.05E-03	4.83E-05	4.66E+01	1.00E+00	2.10E+02
241-AN-107	5.37E+01	5.11E-01	8.21E-03	3.16E-02	2.29E-03	2.09E+02	4.00E+02	2.10E+02
241-AP-101	7.51E-02	1.48E-04	2.10E-05	8.06E-05	5.85E-06	1.07E+02	1.25E+02	4.39E+02
241-AP-102	2.77E-01	1.24E-03	3.75E-05	2.22E-04	5.75E-06	1.72E+02	7.52E+01	4.39E+02
241-AP-103	1.78E+00	8.18E-03	1.16E-04	6.91E-04	2.14E-05	1.70E+02	1.00E+00	2.50E+02
241-AP-104	1.30E+00	1.81E-02	1.99E-04	1.17E-03	3.10E-05	1.45E+02	3.14E+00	1.33E+02
241-AP-105	2.14E-01	5.45E-04	3.65E-05	2.22E-04	1.26E-05	1.07E+02	7.33E+00	3.24E+02
241-AP-106	9.84E-01	5.02E-04	1.05E-05	6.11E-05	1.72E-06	1.45E+02	5.33E+00	6.75E+01
241-AP-107	7.85E-01	4.07E-04	9.79E-06	6.12E-05	1.35E-06	1.04E+02	5.00E+00	1.14E+03
241-AP-108	5.01E-01	2.34E-04	4.66E-05	2.30E-04	1.71E-05	1.40E+02	2.66E+01	9.63E+02
241-AW-101	2.55E-01	1.77E-04	7.27E-05	2.80E-04	2.03E-05	2.58E+02	5.15E+00	1.00E+01
241-AW-102	6.96E-01	3.58E-04	1.35E-05	7.69E-05	8.46E-06	9.91E+01	2.55E+00	7.43E+01
241-AW-103	1.77E-01	4.11E-05	2.04E-05	9.58E-05	8.66E-06	9.01E+01	1.38E+02	5.12E+02
241-AW-104	1.21E+00	1.16E-03	1.88E-05	1.05E-04	3.36E-06	1.77E+02	6.00E+00	1.69E+02
241-AW-105	2.08E-02	6.03E-05	6.09E-05	2.16E-04	2.15E-05	9.42E+00	4.28E+01	1.01E+03
241-AW-106	3.56E-01	5.80E-04	2.87E-05	1.82E-04	3.82E-06	1.19E+02	2.78E+01	3.55E+02
241-AY-101	7.81E-01	2.22E-03	3.36E-03	1.44E-02	6.00E-04	3.90E+01	5.00E+00	1.13E+02
241-AY-102	9.65E-01	1.79E-04	2.91E-04	1.34E-03	2.16E-04	1.71E+01	4.29E+00	7.37E+01
241-AZ-101	7.06E-01	1.17E-04	3.26E-04	1.14E-03	1.18E-04	1.27E+03	1.00E+00	1.25E+02
241-AZ-102	1.77E+00	5.62E-04	1.80E-03	6.57E-03	6.36E-04	8.50E+02	5.53E+00	4.38E+02
241-SY-101	1.69E+00	4.37E-04	1.76E-05	1.11E-04	2.36E-06	9.07E+01	4.00E+02	1.04E+03
241-SY-102	9.28E-02	2.96E-04	1.36E-05	8.29E-05	1.99E-06	5.97E+01	1.17E+01	1.15E+03
241-SY-103	2.05E+00	6.92E-03	7.97E-06	3.71E-05	1.30E-06	2.92E+02	5.94E+01	1.29E+03

Notes:

[a]Input data were taken from Appendix B (hydrogen generation rate input data), which was from the Best-Basis Inventory data download on September 27, 2005.

[b]Input data were taken from Appendix C (ammonia input data), which was prepared in 2001.

RPP-5926, 2005, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, Rev. 5, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table A-1d. Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations from Appendix B and C of RPP-5926, Rev. 5.[a]

Supernatant waste	Bulk density D (g/mL)	Liquid density DL (g/ml)	Waste[b] volume (kL)	Bulk water [H2O] (wt%)	Liquid water [H2O] (wt%)	Waste temp. Tw (°C)	Dome temp. Td (°C)	Headspace[b] volume (ft^3)
241-AN-101	1.41	1.41	98	52%	52%	27	25	2,135
241-AN-102	1.41	1.41	98	43%	43%	32	31	2,135
241-AN-103	1.48	1.48	98	47%	47%	38	32	2,135
241-AN-104	1.40	1.40	98	51%	51%	35	32	2,135
241-AN-105	1.42	1.42	98	50%	50%	32	30	2,135
241-AN-106	1.11	1.11	98	82%	82%	24	22	2,135
241-AN-107	1.43	1.43	98	52%	52%	33	31	2,135
241-AP-101	1.30	1.30	98	64%	64%	21	22	2,135
241-AP-102	1.39	1.39	98	59%	59%	21	19	2,135
241-AP-103	1.35	1.35	98	57%	57%	21	23	2,135
241-AP-104	1.28	1.28	98	66%	66%	23	22	2,135
241-AP-105	1.27	1.27	98	71%	71%	19	18	2,135
241-AP-106	1.21	1.21	98	72%	72%	24	19	2,135
241-AP-107	1.28	1.28	98	66%	66%	20	19	2,135
241-AP-108	1.43	1.43	98	53%	53%	32	41	2,135
241-AW-101	1.47	1.47	98	44%	44%	32	21	2,135
241-AW-102	1.26	1.26	98	67%	67%	22	22	2,135
241-AW-103	1.24	1.24	98	66%	66%	21	21	2,135
241-AW-104	1.35	1.35	98	55%	67%	28	25	2,135
241-AW-105	1.06	1.06	98	90%	90%	19	20	2,135
241-AW-106	1.30	1.30	98	72%	72%	26	25	2,135
241-AY-101	1.19	1.19	98	80%	80%	42	34	2,135
241-AY-102	1.17	1.17	98	83%	83%	49	40	2,135
241-AZ-101	1.24	1.24	98	73%	73%	72	72	2,135
241-AZ-102	1.11	1.11	98	83%	83%	49	49	2,135
241-SY-101	1.30	1.30	98	65%	65%	23	20	2,135
241-SY-102	1.27	1.27	98	65%	65%	26	26	2,135
241-SY-103	1.47	1.47	98	43%	43%	28	25	2,135

Notes:

[a]RPP-5926, 2005, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, Rev. 5, CH2M HILL Hanford Group, Inc., Richland, Washington.

[b]These values are for evaporator vessel C-A-1.

RGS = retained gas sampler.

Table A-2. Updated Ammonia Liquid Data Based on TWINS Database.

Tanks	RPP-5926 NH_3 prepared in 1999 (µg/mL)	Maximum supernatant NH_3 after 1999* (µg/mL)	NH_3 used in this calculation (µg/mL)
241-AN-101	4.00E+01	1.68E+02	**1.68E+02**
241-AN-102	2.10E+02	NA	2.10E+02
241-AN-103	3.45E+02	NA	3.45E+02
241-AN-104	2.46E+02	NA	2.46E+02
241-AN-105	2.10E+02	NA	2.10E+02
241-AN-106	2.10E+02	1.01E+02	2.10E+02
241-AN-107	2.10E+02	NA	2.10E+02
241-AP-101	4.39E+02	1.13E+02	4.39E+02
241-AP-102	4.39E+02	NA	4.39E+02
241-AP-103	2.50E+02	NA	2.50E+02
241-AP-104	1.33E+02	NA	1.33E+02
241-AP-105	3.24E+02	NA	3.24E+02
241-AP-106	6.75E+01	NA	6.75E+01
241-AP-107	1.06E+03	1.14E+03	**1.14E+03**
241-AP-108	8.00E+02	9.63E+02	**9.63E+02**
241-AW-101	1.00E+01	NA	1.00E+01
241-AW-102	7.43E+01	NA	7.43E+01
241-AW-103	5.12E+02	NA	5.12E+02
241-AW-104	1.69E+02	8.03E+01	1.69E+02
241-AW-105	1.01E+03	NA	1.01E+03
241-AW-106	3.55E+02	1.11E+02	3.55E+02
241-AY-101	1.13E+02	NA	1.13E+02
241-AY-102	7.37E+01	NA	7.37E+01
241-AZ-101	1.25E+02	NA	1.25E+02
241-AZ-102	4.38E+02	NA	4.38E+02
241-SY-101	1.04E+03	NA	1.04E+03
241-SY-102	1.15E+03	1.15E+03	1.15E+03
241-SY-103	1.29E+03	NA	1.29E+03

Notes:

*Data compiled from TWINs database updated May 2006.

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TWINS, Best Basis Inventory, available at http://twins.pnl.gov/twins.htm, Pacific Northwest National Laboratory, Richland, Washington.

NA = not applicable.

Table A-3a. Concentrated Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations at Target SpG of 1.6.

Supernatant waste	**Concen. ratio for final density is 1.6 (V_0/V)**	**Na in liquid [Na] (µg/mL)**	**Al in liquid [Al] (µg/mL)**	**Fe+3 in liquid [Fe+3] (µg/mL)**	**Cr+3 in liquid [Cr+3] (µg/mL)**	**Ni+2 in liquid [Ni+2] (µg/mL)**	**K+1 in liquid [K+1] (µg/mL)**	**TOC in liquid [TOC] (µg/mL)**
241-AN-101	1.46	3.13E+05	2.77E+04	9.25E+00	1.77E+02	5.28E+00	3.93E+03	7.47E+03
241-AN-102	1.46	3.03E+05	1.92E+04	7.17E+01	4.35E+02	6.10E+02	4.22E+03	3.53E+04
241-AN-103	1.25	3.37E+05	3.74E+04	3.76E+01	7.08E+02	1.50E+01	2.10E+04	3.81E+03
241-AN-104	1.50	3.88E+05	5.85E+04	4.51E+01	5.04E+02	1.80E+01	1.00E+04	4.71E+03
241-AN-105	1.43	3.53E+05	5.95E+04	3.53E+01	3.17E+02	1.42E+01	9.29E+03	3.95E+03
241-AN-106	5.45	2.45E+05	2.25E+04	9.65E+00	5.41E+02	1.52E+03	3.25E+04	1.14E+04
241-AN-107	1.40	2.90E+05	1.57E+03	2.33E+03	2.40E+02	7.69E+02	2.53E+03	4.53E+04
241-AP-101	2.00	2.59E+05	1.46E+04	5.00E+00	2.86E+02	1.58E+01	6.24E+04	3.79E+03
241-AP-102	1.54	2.99E+05	4.74E+04	5.88E+00	9.52E+02	4.09E+01	1.98E+03	4.63E+03
241-AP-103	1.71	3.05E+05	3.14E+04	5.15E+01	6.37E+02	2.09E+02	2.28E+04	1.24E+04
241-AP-104	2.14	2.75E+05	3.59E+04	2.23E+02	2.94E+03	1.68E+02	4.52E+03	8.90E+03
241-AP-105	2.22	2.97E+05	4.27E+04	6.69E+01	1.14E+03	5.65E+01	2.74E+04	3.32E+03
241-AP-106	2.86	2.96E+05	3.86E+04	3.23E+02	4.47E+03	2.16E+02	8.91E+03	9.90E+03
241-AP-107	2.16	2.64E+05	2.99E+04	2.18E+01	1.42E+03	5.10E+00	3.42E+03	5.04E+03
241-AP-108	1.40	2.78E+05	3.32E+04	1.41E+01	1.15E+03	5.61E+00	3.98E+03	5.84E+03
241-AW-101	1.28	2.97E+05	3.77E+04	2.30E+01	1.43E+02	7.79E+00	5.26E+04	3.34E+03
241-AW-102	2.31	2.68E+05	3.06E+04	1.60E+01	1.11E+03	4.38E+00	3.05E+03	5.20E+03
241-AW-103	2.50	4.06E+05	4.04E+04	1.39E+01	6.32E+01	1.27E+01	3.57E+04	5.15E+03
241-AW-104	1.71	2.91E+05	4.36E+04	3.19E+00	3.77E+00	1.27E+00	2.86E+03	7.40E+03
241-AW-105	10.00	2.26E+05	1.43E+03	4.61E+01	2.12E+01	9.91E+00	1.99E+04	4.08E+03
241-AW-106	2.00	2.89E+05	4.20E+04	4.36E+01	2.94E+03	1.68E+01	1.13E+04	3.53E+03
241-AY-101	3.16	3.66E+05	1.50E+04	3.79E+01	3.32E+02	1.86E+02	2.41E+03	4.27E+03
241-AY-102	3.51	2.00E+05	4.04E+03	3.55E+01	1.02E+02	1.41E+01	1.36E+03	2.87E+03
241-AZ-101	2.50	2.80E+05	1.53E+04	5.60E+01	1.81E+03	2.00E+01	1.19E+04	1.28E+03
241-AZ-102	5.45	3.36E+05	1.86E+03	5.45E+00	4.02E+03	9.55E+00	1.75E+04	1.09E+04
241-SY-101	2.00	2.75E+05	1.89E+04	7.94E+02	1.04E+04	4.03E+02	8.28E+03	4.61E+03
241-SY-102	2.22	2.72E+05	1.87E+04	3.13E+01	5.36E+02	1.12E+02	3.40E+03	2.76E+03
241-SY-103	1.28	2.74E+05	4.80E+04	2.68E+01	4.21E+01	6.26E+01	4.99E+03	7.94E+03

Table A-3b. Concentrated Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations at Target SpG of 1.6.

Supernatant waste	OH^{-1} in liquid [OH] (µg/mL)	NO_2^{-1} in liquid [NO_2^{-1}] (µg/mL)	NO3 in liquid [NO3] (µg/mL)	CO_3^{-2} in liquid [CO3-2] (µg/mL)	PO_4^{-3} in liquid [PO4-3] (µg/mL)	SO_4^{-2} in liquid [SO4-2] (µg/mL)	F^{-1} in liquid [F^{-1}] (µg/mL)	Cl^{-1} in liquid [Cl^{-1}] (µg/mL)
241-AN-101	5.13E+04	1.70E+05	2.37E+05	1.41E+04	2.33E+03	1.99E+03	4.22E+02	3.42E+03
241-AN-102	1.30E+04	1.27E+05	3.06E+05	1.02E+05	8.07E+03	2.24E+04	2.79E+03	6.02E+03
241-AN-103	8.40E+04	1.63E+05	1.61E+05	7.25E+03	2.06E+03	1.81E+03	8.25E+02	1.22E+04
241-AN-104	9.79E+04	1.79E+05	2.84E+05	1.60E+04	4.06E+03	5.31E+03	1.23E+02	1.21E+04
241-AN-105	8.53E+04	1.69E+05	2.23E+05	1.69E+04	1.75E+03	4.07E+03	4.37E+02	1.41E+04
241-AN-106	2.78E+04	1.09E+05	1.38E+05	1.19E+05	1.10E+04	3.00E+04	2.79E+04	5.24E+03
241-AN-107	2.51E+04	9.31E+04	2.92E+05	1.05E+05	4.10E+03	1.25E+04	5.83E+03	2.82E+03
241-AP-101	7.96E+04	8.15E+04	2.35E+05	6.46E+04	2.04E+03	8.06E+03	5.80E+03	3.96E+03
241-AP-102	4.93E+04	1.51E+05	2.57E+05	4.10E+04	1.78E+04	6.95E+03	2.58E+02	4.20E+03
241-AP-103	2.86E+04	1.38E+05	2.55E+05	1.29E+05	5.93E+03	7.71E+03	3.58E+03	4.83E+03
241-AP-104	4.21E+04	1.37E+05	2.16E+05	4.14E+04	8.27E+03	8.23E+03	8.89E+02	1.18E+04
241-AP-105	5.76E+04	1.05E+05	2.35E+05	2.50E+05	7.03E+03	1.51E+04	1.05E+04	1.21E+04
241-AP-106	2.11E+04	1.18E+05	2.02E+05	5.38E+04	7.90E+03	9.14E+03	1.92E+03	1.41E+04
241-AP-107	3.92E+04	1.11E+05	2.42E+05	9.84E+03	1.05E+04	5.21E+03	1.56E+03	4.95E+03
241-AP-108	5.52E+04	1.12E+05	2.45E+05	1.77E+04	4.75E+03	3.80E+03	1.35E+03	3.99E+03
241-AW-101	1.27E+05	1.35E+05	2.18E+05	1.17E+04	1.27E+03	1.61E+03	1.23E+03	9.32E+03
241-AW-102	4.26E+04	1.12E+05	2.45E+05	5.34E+03	1.44E+03	3.97E+03	1.25E+03	3.88E+03
241-AW-103	3.94E+04	1.07E+05	3.26E+05	1.17E+04	1.48E+02	1.68E+03	4.20E+04	3.45E+02
241-AW-104	4.34E+04	1.28E+05	1.93E+05	1.24E+04	5.02E+02	1.12E+03	2.26E+02	4.10E+02
241-AW-105	4.38E+04	2.55E+04	2.46E+05	1.62E+04	1.85E+03	3.01E+03	4.81E+03	2.45E+03
241-AW-106	5.44E+04	1.10E+05	2.28E+05	5.68E+04	2.94E+03	1.03E+04	2.46E+03	1.03E+04
241-AY-101	1.09E+05	1.06E+05	1.47E+04	1.09E+05	3.63E+03	1.85E+04	5.49E+02	2.01E+03
241-AY-102	2.72E+04	1.05E+05	1.37E+03	1.71E+05	1.06E+04	8.15E+03	6.04E+02	5.62E+02
241-AZ-101	2.87E+04	1.55E+05	1.33E+05	8.55E+04	3.34E+03	3.76E+04	4.38E+03	3.77E+02
241-AZ-102	1.34E+04	2.22E+05	4.49E+04	1.91E+05	2.71E+03	1.01E+05	6.22E+03	4.18E+02
241-SY-101	7.48E+04	8.29E+04	2.06E+05	6.87E+04	9.88E+03	8.38E+03	1.10E+03	2.22E+04
241-SY-102	2.14E+04	5.44E+04	3.66E+05	2.91E+04	7.73E+03	6.47E+03	3.36E+02	1.03E+04
241-SY-103	3.81E+04	1.95E+05	2.14E+05	4.39E+04	3.98E+03	5.21E+03	4.48E+02	1.48E+04

Table A-3c. Concentrated Input Data for Hydrogen Generation and Ammonia Equilibrium Model Calculations at Target SpG of 1.6.

Supernatant waste	^{90}Sr in waste [Sr] (µCi/g)	^{241}Am in waste [Am241] (µCi/g)	^{240}Pu in waste [Pu240] (µCi/g)	^{239}Pu in waste [Pu240] (µCi/g)	^{238}Pu in waste [Pu238] (µCi/g)	^{137}Cs in waste [Cs] (µCi/g)	Liquid NH_3 (µg/mL)	Liquid water [H2O] (wt%)
241-AN-101	1.64E+00	8.48E-04	1.33E-05	8.01E-05	1.98E-06	2.56E+02	5.05E+01	37%
241-AN-102	7.23E+01	1.48E-01	1.13E-03	4.35E-03	3.16E-04	3.59E+02	6.30E+01	26%
241-AN-103	1.38E-02	4.75E-03	5.17E-05	1.99E-04	1.45E-05	4.92E+02	1.04E+02	38%
241-AN-104	7.67E-02	3.29E-04	1.76E-05	6.77E-05	4.90E-06	4.61E+02	7.38E+01	36%
241-AN-105	3.10E-02	1.28E-02	1.40E-04	5.37E-04	3.90E-05	2.61E+02	6.30E+01	36%
241-AN-106	2.16E+00	1.58E-03	1.79E-03	1.15E-02	1.83E-04	1.77E+02	6.30E+01	32%
241-AN-107	6.69E+01	6.37E-01	1.02E-02	3.94E-02	2.86E-03	2.61E+02	6.30E+01	40%
241-AP-101	1.22E-01	2.41E-04	3.41E-05	1.31E-04	9.51E-06	1.74E+02	1.32E+02	41%
241-AP-102	3.70E-01	1.66E-03	5.01E-05	2.97E-04	7.69E-06	2.29E+02	1.32E+02	45%
241-AP-103	2.58E+00	1.18E-02	1.67E-04	9.99E-04	3.09E-05	2.45E+02	7.50E+01	38%
241-AP-104	2.24E+00	3.10E-02	3.41E-04	2.00E-03	5.31E-05	2.48E+02	3.99E+01	42%
241-AP-105	3.77E-01	9.61E-04	6.43E-05	3.91E-04	2.23E-05	1.88E+02	9.72E+01	50%
241-AP-106	2.13E+00	1.08E-03	2.27E-05	1.32E-04	3.71E-06	3.13E+02	2.03E+01	40%
241-AP-107	1.35E+00	7.03E-04	1.69E-05	1.06E-04	2.33E-06	1.79E+02	3.42E+02	41%
241-AP-108	6.25E-01	2.92E-04	5.81E-05	2.86E-04	2.14E-05	1.75E+02	2.89E+02	42%
241-AW-101	3.00E-01	2.08E-04	8.53E-05	3.28E-04	2.38E-05	3.02E+02	3.00E+00	34%
241-AW-102	1.27E+00	6.50E-04	2.45E-05	1.40E-04	1.54E-05	1.80E+02	2.23E+01	41%
241-AW-103	3.43E-01	7.97E-05	3.94E-05	1.86E-04	1.68E-05	1.75E+02	1.54E+02	34%
241-AW-104	1.74E+00	1.68E-03	2.72E-05	1.52E-04	4.86E-06	2.56E+02	5.07E+01	52%
241-AW-105	1.38E-01	3.99E-04	4.04E-04	1.43E-03	1.42E-04	6.24E+01	3.03E+02	33%
241-AW-106	5.79E-01	9.43E-04	4.67E-05	2.96E-04	6.22E-06	1.93E+02	1.07E+02	55%
241-AY-101	1.83E+00	5.20E-03	7.89E-03	3.38E-02	1.41E-03	9.17E+01	3.39E+01	52%
241-AY-102	2.48E+00	4.61E-04	7.49E-04	3.45E-03	5.54E-04	4.39E+01	2.21E+01	56%
241-AZ-101	1.37E+00	2.27E-04	6.32E-04	2.21E-03	2.29E-04	2.46E+03	3.75E+01	48%
241-AZ-102	6.69E+00	2.13E-03	6.80E-03	2.49E-02	2.41E-03	3.22E+03	1.31E+02	36%
241-SY-101	2.75E+00	7.11E-04	2.85E-05	1.80E-04	3.83E-06	1.47E+02	3.13E+02	42%
241-SY-102	1.64E-01	5.22E-04	2.40E-05	1.46E-04	3.51E-06	1.05E+02	3.45E+02	38%
241-SY-103	2.40E+00	8.12E-03	9.34E-06	4.35E-05	1.52E-06	3.42E+02	3.87E+02	33%

APPENDIX B

FLAMMABILITY ANALYSIS RESULTS ON EVAPORATOR VESSEL C-A-1

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APPENDIX B

FLAMMABILITY ANALYSIS RESULTS ON EVAPORATOR VESSEL C-A-1

Table B-1. Feed Waste Condition and Time to Lower Flammability Limit for Evaporator Vessel at 62% Filled.

Tanks	Na in liquid [Na] (μg/mL)	NO_3 in liquid [NO3] (μg/mL)	NO_2 in liquid [NO2] (μg/mL)	Liquid density DL (g/ml)	Liquid NH3 (μg/mL)	Liquid water [H2O] (wt%)	Waste temp. Tw (°C)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)
241-AN-101	2.14E+05	1.62E+05	1.16E+05	1.41	168	52%	27	243	977
241-AN-102	2.07E+05	2.09E+05	8.71E+04	1.41	210	43%	32	54	221
241-AN-103	2.70E+05	1.29E+05	1.30E+05	1.48	345	47%	38	125	534
241-AN-104	2.58E+05	1.89E+05	1.19E+05	1.40	246	51%	35	153	636
241-AN-105	2.47E+05	1.56E+05	1.19E+05	1.42	210	50%	32	220	908
241-AN-106	4.49E+04	2.53E+04	2.01E+04	1.11	210	82%	24	402	1631
241-AN-107	2.08E+05	2.09E+05	6.67E+04	1.43	210	52%	33	69	279
241-AP-101	1.29E+05	1.18E+05	4.08E+04	1.30	439	64%	21	450	1833
241-AP-102	1.94E+05	1.67E+05	9.82E+04	1.39	439	59%	21	359	1475
241-AP-103	1.78E+05	1.49E+05	8.04E+04	1.35	250	57%	21	280	1136
241-AP-104	1.28E+05	1.01E+05	6.39E+04	1.28	133	66%	23	301	1216
241-AP-105	1.34E+05	1.06E+05	4.73E+04	1.27	324	71%	19	464	1892
241-AP-106	1.03E+05	7.07E+04	4.14E+04	1.21	68	72%	24	290	1168
241-AP-107	1.22E+05	1.12E+05	5.14E+04	1.28	1140	66%	20	415	1716
241-AP-108	1.99E+05	1.76E+05	8.02E+04	1.43	963	53%	32	199	843
241-AW-101	2.33E+05	1.71E+05	1.05E+05	1.47	10	44%	32	237	952
241-AW-102	1.16E+05	1.06E+05	4.87E+04	1.26	74	67%	22	417	1681
241-AW-103	1.62E+05	1.31E+05	4.30E+04	1.24	512	66%	21	519	2000
241-AW-104	1.70E+05	1.12E+05	7.45E+04	1.35	169	67%	28	237	960
241-AW-105	2.26E+04	2.46E+04	2.55E+03	1.06	1010	90%	19	713	2000
241-AW-106	1.44E+05	1.14E+05	5.49E+04	1.30	355	72%	26	385	1574
241-AY-101	1.16E+05	4.65E+03	3.35E+04	1.19	113	80%	42	347	1409
241-AY-102	5.69E+04	3.91E+02	2.99E+04	1.17	74	83%	49	377	1532
241-AZ-101	1.12E+05	5.32E+04	6.20E+04	1.24	125	73%	72	27	112
241-AZ-102	6.15E+04	8.23E+03	4.07E+04	1.11	438	83%	49	34	143
241-SY-101	1.37E+05	1.03E+05	4.14E+04	1.30	1044	65%	23	441	1837
241-SY-102	1.22E+05	1.65E+05	2.45E+04	1.27	1150	65%	26	540	2000
241-SY-103	2.15E+05	1.68E+05	1.52E+05	1.47	1290	43%	28	135	606

Notes:

In this calculation, the ammonia concentration is 30% of the raw waste concentration, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

LFL = lower flammability limit.

Table B-2. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 120 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.99E-03	1.50E-07	6.89E-08	6.69E-09	0.3%	39.0	233	35.8	145	2.5
241-AN-102	8.64E-03	1.78E-07	2.93E-07	2.91E-08	0.4%	8.5	37	8.4	34	10.6
241-AN-103	5.79E-03	3.54E-07	4.55E-08	4.35E-09	1.1%	60.1	865	52.6	218	1.7
241-AN-104	3.96E-03	2.80E-07	6.16E-08	5.95E-09	1.2%	42.4	284	38.6	160	2.3
241-AN-105	4.60E-03	2.31E-07	4.92E-08	4.72E-09	0.9%	55.4	528	49.0	202	1.8
241-AN-106	7.54E-03	1.93E-07	9.29E-08	9.09E-09	0.4%	28.1	146	26.4	107	3.4
241-AN-107	1.00E-02	1.61E-07	1.65E-07	1.63E-08	0.3%	15.4	70	14.9	60	6.0
241-AP-101	8.77E-03	3.69E-07	2.91E-08	2.71E-09	0.7%	104.8	not occur	83.6	342	1.1
241-AP-102	6.81E-03	4.22E-07	5.27E-08	5.07E-09	1.1%	50.7	413	45.3	188	2.0
241-AP-103	6.69E-03	2.42E-07	1.16E-07	1.14E-08	0.6%	22.0	108	21.0	86	4.2
241-AP-104	8.28E-03	1.16E-07	8.90E-08	8.70E-09	0.2%	29.7	156	27.8	112	3.2
241-AP-105	4.25E-03	3.63E-07	3.67E-08	3.47E-09	1.5%	75.6	not occur	64.1	269	1.4
241-AP-106	7.72E-03	6.11E-08	1.03E-07	1.01E-08	0.1%	25.6	127	24.1	97	3.7
241-AP-107	9.64E-03	8.97E-07	4.77E-08	4.57E-09	1.6%	55.4	301	49.0	165	1.8
241-AP-108	8.88E-03	8.03E-07	5.62E-08	5.42E-09	1.6%	46.1	344	41.6	175	2.1
241-AW-101	6.05E-03	1.01E-08	3.79E-08	3.59E-09	0.0%	78.3	not occur	66.0	265	1.3
241-AW-102	9.69E-03	5.82E-08	4.94E-08	4.74E-09	0.1%	57.2	536	50.4	203	1.8
241-AW-103	4.92E-03	5.52E-07	5.25E-08	5.05E-09	2.0%	48.8	407	43.8	187	2.0
241-AW-104	7.82E-03	1.52E-07	7.98E-08	7.78E-09	0.3%	33.2	183	30.9	125	2.9
241-AW-105	1.24E-02	6.24E-07	1.34E-08	1.14E-09	0.9%	379.0	not occur	182.0	750	0.5
241-AW-106	7.28E-03	3.31E-07	3.88E-08	3.68E-09	0.8%	73.3	not occur	62.4	256	1.4
241-AY-101	4.33E-03	1.26E-07	2.98E-08	2.78E-09	0.5%	102.7	not occur	82.3	335	1.0
241-AY-102	8.37E-03	6.38E-08	1.37E-08	1.17E-09	0.1%	383.7	not occur	182.9	736	0.5
241-AZ-101	7.97E-03	1.11E-07	5.07E-08	4.87E-09	0.2%	55.2	483	48.9	197	1.8
241-AZ-102	5.00E-03	4.70E-07	1.64E-07	1.62E-08	1.66%	14.7	70	14.2	60	6.3
241-SY-101	8.52E-03	8.94E-07	3.67E-08	3.47E-09	1.85%	74.4	not occur	63.2	268	1.4
241-SY-102	1.15E-02	7.73E-07	2.25E-08	2.05E-09	1.18%	144.2	not occur	106.2	441	0.8
241-SY-103	7.36E-03	1.20E-06	9.25E-08	9.05E-09	2.86%	25.3	142	23.9	105	3.7

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-3. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 130 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.62E-03	1.54E-07	1.16E-07	1.14E-08	0.4%	22	106	20.9	85	4.3
241-AN-102	8.26E-03	1.83E-07	4.93E-07	4.91E-08	0.4%	5	21	4.9	20	18.2
241-AN-103	5.48E-03	3.60E-07	7.31E-08	7.11E-09	1.2%	35	202	32.0	133	2.8
241-AN-104	3.72E-03	2.84E-07	1.02E-07	9.98E-09	1.4%	24	124	22.8	95	3.9
241-AN-105	4.34E-03	2.34E-07	8.22E-08	8.03E-09	1.0%	31	169	28.7	118	3.1
241-AN-106	7.05E-03	1.99E-07	1.58E-07	1.56E-08	0.5%	16	72	15.2	62	5.9
241-AN-107	9.52E-03	1.67E-07	2.68E-07	2.66E-08	0.3%	9	40	9.0	36	9.9
241-AP-101	8.39E-03	3.80E-07	4.73E-08	4.53E-09	0.8%	57	584	50.3	206	1.8
241-AP-102	6.47E-03	4.31E-07	8.81E-08	8.62E-09	1.2%	28	152	26.5	110	3.4
241-AP-103	6.35E-03	2.48E-07	1.97E-07	1.95E-08	0.7%	12	56	12.1	49	7.4
241-AP-104	7.86E-03	1.19E-07	1.50E-07	1.48E-08	0.3%	17	77	16.1	65	5.5
241-AP-105	4.00E-03	3.68E-07	6.09E-08	5.89E-09	1.6%	41	278	37.7	159	2.4
241-AP-106	7.28E-03	6.30E-08	1.74E-07	1.72E-08	0.2%	14	65	14.0	56	6.3
241-AP-107	9.04E-03	9.40E-07	7.96E-08	7.77E-09	1.9%	31	175	28.5	121	3.1
241-AP-108	8.45E-03	8.29E-07	9.48E-08	9.28E-09	1.8%	25	136	24.1	102	3.7
241-AW-101	5.74E-03	1.03E-08	6.14E-08	5.95E-09	0.0%	44	282	39.9	160	2.2
241-AW-102	9.10E-03	6.09E-08	8.27E-08	8.07E-09	0.1%	32	170	29.6	119	3.0
241-AW-103	4.65E-03	5.61E-07	8.92E-08	8.73E-09	2.2%	27	147	25.1	108	3.5
241-AW-104	7.35E-03	1.57E-07	1.35E-07	1.33E-08	0.4%	19	88	17.9	73	5.0
241-AW-105	1.15E-02	6.78E-07	2.11E-08	1.91E-09	1.1%	156	not occur	112.3	465	0.8
241-AW-106	6.92E-03	3.39E-07	6.44E-08	6.24E-09	0.9%	40	253	36.8	151	2.4
241-AY-101	4.08E-03	1.28E-07	5.02E-08	4.82E-09	0.6%	54	466	47.9	195	1.7
241-AY-102	7.49E-03	6.78E-08	2.18E-08	1.98E-09	0.2%	157	not occur	112.7	454	0.8
241-AZ-101	7.44E-03	1.15E-07	6.00E-08	5.80E-09	0.3%	45	295	40.5	163	2.2
241-AZ-102	4.72E-03	4.78E-07	2.23E-07	2.21E-08	1.8%	10	48	10.2	43	8.7
241-SY-101	8.13E-03	9.19E-07	6.10E-08	5.90E-09	2.0%	40	275	37.0	158	2.4
241-SY-102	1.09E-02	8.17E-07	3.69E-08	3.49E-09	1.3%	74	not occur	63.1	263	1.4
241-SY-103	7.01E-03	1.23E-06	1.54E-07	1.53E-08	3.1%	14	72	13.9	62	6.4

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG. It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-4. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 140 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.34E-03	1.56E-07	1.94E-07	1.92E-08	0.4%	12.6	56	12.3	50	7.3
241-AN-102	7.97E-03	1.87E-07	8.23E-07	8.21E-08	0.4%	2.9	12	2.9	12	30.9
241-AN-103	5.26E-03	3.65E-07	1.19E-07	1.17E-08	1.3%	20.1	99	19.3	80	4.6
241-AN-104	3.56E-03	2.86E-07	1.69E-07	1.67E-08	1.5%	13.9	65	13.4	56	6.6
241-AN-105	4.15E-03	2.37E-07	1.38E-07	1.36E-08	1.0%	17.5	83	16.8	69	5.3
241-AN-106	6.70E-03	2.03E-07	2.67E-07	2.65E-08	0.6%	9.0	39	8.8	36	10.1
241-AN-107	9.18E-03	1.71E-07	4.35E-07	4.33E-08	0.3%	5.5	23	5.5	22	16.3
241-AP-101	8.10E-03	3.87E-07	7.78E-08	7.59E-09	0.9%	32.2	179	30.0	123	3.0
241-AP-102	6.22E-03	4.38E-07	1.48E-07	1.46E-08	1.3%	16.1	76	15.5	65	5.7
241-AP-103	6.10E-03	2.51E-07	3.34E-07	3.32E-08	0.8%	7.1	31	7.0	29	12.7
241-AP-104	7.58E-03	1.22E-07	2.53E-07	2.51E-08	0.3%	9.6	42	9.4	38	9.4
241-AP-105	3.83E-03	3.71E-07	1.02E-07	9.96E-09	1.8%	23.2	121	22.1	93	4.0
241-AP-106	6.97E-03	6.43E-08	2.92E-07	2.90E-08	0.2%	8.4	36	8.2	33	10.8
241-AP-107	8.59E-03	9.71E-07	1.33E-07	1.31E-08	2.1%	17.3	85	16.6	71	5.4
241-AP-108	8.15E-03	8.47E-07	1.59E-07	1.58E-08	1.9%	14.4	69	14.0	59	6.4
241-AW-101	5.51E-03	1.04E-08	1.01E-07	9.89E-09	0.0%	25.3	125	23.9	96	3.7
241-AW-102	8.68E-03	6.29E-08	1.38E-07	1.37E-08	0.1%	18.0	83	17.3	70	5.1
241-AW-103	4.45E-03	5.67E-07	1.51E-07	1.49E-08	2.3%	15.0	73	14.5	62	6.1
241-AW-104	7.03E-03	1.60E-07	2.27E-07	2.25E-08	0.4%	10.7	47	10.5	42	8.5
241-AW-105	1.08E-02	7.23E-07	3.40E-08	3.20E-09	1.2%	80.8	not occur	67.8	282	1.3
241-AW-106	6.66E-03	3.45E-07	1.07E-07	1.05E-08	0.9%	22.7	114	21.6	89	4.1
241-AY-101	3.90E-03	1.29E-07	8.43E-08	8.24E-09	0.6%	29.9	159	27.9	114	2.9
241-AY-102	6.80E-03	7.09E-08	3.53E-08	3.34E-09	0.2%	81.2	not occur	68.0	274	1.3
241-AZ-101	7.07E-03	1.18E-07	7.45E-08	7.26E-09	0.3%	34.5	193	32.0	129	2.8
241-AZ-102	4.52E-03	4.83E-07	3.08E-07	3.06E-08	1.95%	7.3	33	7.2	31	12.3
241-SY-101	7.85E-03	9.37E-07	1.02E-07	9.99E-09	2.17%	22.8	120	21.6	93	4.1
241-SY-102	1.04E-02	8.50E-07	6.11E-08	5.92E-09	1.49%	40.7	268	37.2	156	2.4
241-SY-103	6.75E-03	1.25E-06	2.58E-07	2.56E-08	3.36%	8.2	39	8.1	36	11.0

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-5. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 150 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.13E-03	1.59E-07	3.22E-07	3.20E-08	0.4%	7.4	31	7.2	29	12.3
241-AN-102	7.75E-03	1.90E-07	1.36E-06	1.36E-07	0.5%	1.7	7	1.7	7	52.1
241-AN-103	5.08E-03	3.69E-07	1.94E-07	1.92E-08	1.3%	11.9	54	11.6	48	7.7
241-AN-104	3.43E-03	2.88E-07	2.79E-07	2.77E-08	1.6%	8.1	36	8.0	33	11.2
241-AN-105	4.00E-03	2.38E-07	2.29E-07	2.27E-08	1.1%	10.1	45	9.9	41	9.0
241-AN-106	6.48E-03	2.06E-07	4.47E-07	4.45E-08	0.6%	5.2	22	5.2	21	17.2
241-AN-107	8.94E-03	1.74E-07	7.04E-07	7.02E-08	0.4%	3.3	14	3.3	13	26.8
241-AP-101	7.88E-03	3.93E-07	1.28E-07	1.26E-08	0.9%	18.6	89	17.8	73	5.0
241-AP-102	6.03E-03	4.43E-07	2.45E-07	2.44E-08	1.4%	9.3	42	9.1	38	9.7
241-AP-103	5.91E-03	2.54E-07	5.58E-07	5.56E-08	0.8%	4.2	18	4.1	17	21.6
241-AP-104	7.36E-03	1.23E-07	4.22E-07	4.20E-08	0.3%	5.6	24	5.5	22	16.0
241-AP-105	3.69E-03	3.74E-07	1.69E-07	1.67E-08	1.9%	13.4	63	13.0	55	6.8
241-AP-106	6.76E-03	6.51E-08	4.87E-07	4.85E-08	0.2%	4.9	20	4.8	19	18.4
241-AP-107	8.33E-03	9.89E-07	2.22E-07	2.20E-08	2.2%	10.0	46	9.8	42	9.1
241-AP-108	7.93E-03	8.60E-07	2.66E-07	2.64E-08	2.0%	8.3	38	8.2	35	10.9
241-AW-101	5.33E-03	1.05E-08	1.66E-07	1.64E-08	0.0%	14.8	66	14.3	57	6.2
241-AW-102	8.42E-03	6.41E-08	2.31E-07	2.29E-08	0.1%	10.5	45	10.2	41	8.7
241-AW-103	4.29E-03	5.72E-07	2.53E-07	2.51E-08	2.5%	8.6	40	8.5	37	10.5
241-AW-104	6.81E-03	1.63E-07	3.79E-07	3.77E-08	0.4%	6.2	26	6.2	25	14.5
241-AW-105	1.04E-02	7.47E-07	5.53E-08	5.34E-09	1.3%	44.9	320	40.7	170	2.2
241-AW-106	6.46E-03	3.49E-07	1.78E-07	1.77E-08	1.0%	13.1	60	12.8	53	7.0
241-AY-101	3.76E-03	1.30E-07	1.41E-07	1.39E-08	0.6%	17.1	80	16.4	67	4.9
241-AY-102	6.40E-03	7.28E-08	5.77E-08	5.58E-09	0.2%	45.1	299	40.8	164	2.2
241-AZ-101	6.84E-03	1.20E-07	9.71E-08	9.52E-09	0.3%	25.5	128	24.1	97	3.7
241-AZ-102	4.37E-03	4.87E-07	4.33E-07	4.31E-08	2.1%	5.1	23	5.0	21	17.7
241-SY-101	7.63E-03	9.51E-07	1.69E-07	1.67E-08	2.3%	13.1	63	12.7	55	7.0
241-SY-102	1.01E-02	8.70E-07	1.01E-07	9.92E-09	1.6%	23.1	119	22.0	92	4.0
241-SY-103	6.54E-03	1.26E-06	4.28E-07	4.27E-08	3.6%	4.8	22	4.7	21	18.8

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-6. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 150 °F, 100% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.13E-03	5.29E-07	3.22E-07	3.20E-08	1.4%	7.1	31	7.0	29	12.8
241-AN-102	7.75E-03	6.33E-07	1.36E-06	1.36E-07	1.5%	1.6	7	1.6	7	54.5
241-AN-103	5.08E-03	1.23E-06	1.94E-07	1.92E-08	4.5%	10.3	52	10.0	47	8.9
241-AN-104	3.43E-03	9.60E-07	2.79E-07	2.77E-08	5.2%	6.8	35	6.7	32	13.2
241-AN-105	4.00E-03	7.95E-07	2.29E-07	2.27E-08	3.7%	9.0	44	8.8	40	10.1
241-AN-106	6.48E-03	6.87E-07	4.47E-07	4.45E-08	2.0%	4.9	22	4.9	21	18.2
241-AN-107	8.94E-03	5.81E-07	7.04E-07	7.02E-08	1.2%	3.2	14	3.2	13	27.8
241-AP-101	7.88E-03	1.31E-06	1.28E-07	1.26E-08	3.1%	16.9	87	16.2	72	5.5
241-AP-102	6.03E-03	1.48E-06	2.45E-07	2.44E-08	4.5%	8.1	40	7.9	37	11.3
241-AP-103	5.91E-03	8.48E-07	5.58E-07	5.56E-08	2.7%	3.8	17	3.8	17	23.4
241-AP-104	7.36E-03	4.11E-07	4.22E-07	4.20E-08	1.0%	5.4	23	5.4	22	16.5
241-AP-105	3.69E-03	1.25E-06	1.69E-07	1.67E-08	6.3%	10.8	60	10.5	53	8.4
241-AP-106	6.76E-03	2.17E-07	4.87E-07	4.85E-08	0.6%	4.8	20	4.8	19	18.7
241-AP-107	8.33E-03	3.30E-06	2.22E-07	2.20E-08	7.3%	7.7	44	7.6	40	11.8
241-AP-108	7.93E-03	2.87E-06	2.66E-07	2.64E-08	6.7%	6.6	36	6.5	33	13.7
241-AW-101	5.33E-03	3.51E-08	1.66E-07	1.64E-08	0.1%	14.7	66	14.2	57	6.2
241-AW-102	8.42E-03	2.14E-07	2.31E-07	2.29E-08	0.5%	10.3	45	10.1	41	8.8
241-AW-103	4.29E-03	1.91E-06	2.53E-07	2.51E-08	8.2%	6.4	37	6.3	34	14.1
241-AW-104	6.81E-03	5.42E-07	3.79E-07	3.77E-08	1.5%	6.0	26	5.9	25	15.1
241-AW-105	1.04E-02	2.49E-06	5.53E-08	5.34E-09	4.4%	38.5	299	35.4	164	2.5
241-AW-106	6.46E-03	1.16E-06	1.78E-07	1.77E-08	3.3%	11.8	58	11.5	51	7.7
241-AY-101	3.76E-03	4.33E-07	1.41E-07	1.39E-08	2.1%	16.0	78	15.4	66	5.2
241-AY-102	6.40E-03	2.43E-07	5.77E-08	5.58E-09	0.7%	44.1	296	40.0	164	2.2
241-AZ-101	6.84E-03	4.00E-07	9.71E-08	9.52E-09	1.1%	24.7	127	23.4	97	3.8
241-AZ-102	4.37E-03	1.62E-06	4.33E-07	4.31E-08	6.9%	4.0	21	4.0	20	22.4
241-SY-101	7.63E-03	3.17E-06	1.69E-07	1.67E-08	7.7%	9.9	59	9.7	52	9.2
241-SY-102	1.01E-02	2.90E-06	1.01E-07	9.92E-09	5.3%	19.3	114	18.5	89	4.8
241-SY-103	6.54E-03	4.21E-06	4.28E-07	4.27E-08	11.9%	2.9	20	2.9	19	30.7

Notes:

In this calculation, 100% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-7. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.6, Temperature of 150 °F, 100% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m³ per sec)	UCH_4 methane unit rate (mole/m³ per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	5.19E-03	6.09E-07	4.05E-07	4.03E-08	2.2%	5.4	24	5.3	23	16.6
241-AN-102	5.81E-03	7.32E-07	1.72E-06	1.72E-07	2.3%	1.3	5	1.2	5	71.3
241-AN-103	3.30E-03	1.39E-06	2.43E-07	2.41E-08	7.8%	6.8	39	6.7	36	13.3
241-AN-104	1.97E-03	1.06E-06	3.51E-07	3.49E-08	9.9%	4.1	26	4.1	24	21.8
241-AN-105	2.41E-03	8.82E-07	2.88E-07	2.86E-08	6.8%	6.1	33	6.0	31	14.8
241-AN-106	4.90E-03	7.72E-07	5.62E-07	5.60E-08	2.9%	3.7	17	3.7	16	23.9
241-AN-107	7.26E-03	6.68E-07	8.95E-07	8.93E-08	1.7%	2.5	11	2.5	10	36.0
241-AP-101	5.94E-03	1.52E-06	1.60E-07	1.58E-08	4.7%	12.3	65	12.0	56	7.4
241-AP-102	4.14E-03	1.68E-06	3.08E-07	3.06E-08	7.5%	5.4	30	5.4	28	16.5
241-AP-103	4.03E-03	9.65E-07	7.02E-07	7.00E-08	4.4%	2.8	13	2.8	13	32.0
241-AP-104	5.48E-03	4.73E-07	5.31E-07	5.29E-08	1.6%	4.2	18	4.2	18	21.3
241-AP-105	2.17E-03	1.38E-06	2.11E-07	2.10E-08	11.8%	6.0	44	5.9	40	15.0
241-AP-106	5.00E-03	2.47E-07	6.12E-07	6.11E-08	0.9%	3.8	16	3.7	15	23.9
241-AP-107	7.08E-03	3.67E-06	2.78E-07	2.76E-08	9.6%	5.3	33	5.2	31	17.0
241-AP-108	6.06E-03	3.31E-06	3.34E-07	3.33E-08	10.1%	4.3	27	4.2	25	21.1
241-AW-101	3.51E-03	3.97E-08	2.08E-07	2.06E-08	0.2%	11.6	51	11.3	46	7.8
241-AW-102	7.10E-03	2.39E-07	2.89E-07	2.88E-08	0.6%	8.1	35	8.0	33	11.1
241-AW-103	2.64E-03	2.13E-06	3.18E-07	3.16E-08	14.9%	3.0	27	3.0	25	29.5
241-AW-104	5.11E-03	6.14E-07	4.76E-07	4.74E-08	2.2%	4.6	20	4.5	19	19.6
241-AW-105	1.03E-02	2.57E-06	6.89E-08	6.70E-09	4.6%	30.0	199	28.1	131	3.2
241-AW-106	4.54E-03	1.33E-06	2.24E-07	2.22E-08	5.4%	8.5	44	8.3	40	10.7
241-AY-101	2.22E-03	4.79E-07	1.77E-07	1.75E-08	4.0%	11.6	59	11.3	52	7.1
241-AY-102	5.63E-03	2.60E-07	7.18E-08	6.99E-09	0.9%	34.5	198	31.9	131	2.8
241-AZ-101	5.33E-03	4.48E-07	1.13E-07	1.11E-08	1.6%	20.7	104	19.8	83	4.5
241-AZ-102	2.70E-03	1.81E-06	5.55E-07	5.53E-08	12.4%	2.1	15	2.1	15	41.4
241-SY-101	5.69E-03	3.67E-06	2.12E-07	2.10E-08	11.9%	5.9	43	5.8	39	15.2
241-SY-102	9.14E-03	3.20E-06	1.27E-07	1.25E-08	6.5%	14.3	84	13.9	70	6.4
241-SY-103	4.62E-03	4.82E-06	5.39E-07	5.37E-08	19.3%	1.0	15	1.0	14	89.0

Notes:

In this calculation, 100% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-8. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.6, Temperature of 150 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	5.19E-03	1.83E-07	4.05E-07	4.03E-08	0.7%	5.8	25	5.7	23	15.6
241-AN-102	5.81E-03	2.20E-07	1.72E-06	1.72E-07	0.7%	1.3	6	1.3	5	66.5
241-AN-103	3.30E-03	4.16E-07	2.43E-07	2.41E-08	2.3%	9.0	42	8.8	38	10.1
241-AN-104	1.97E-03	3.17E-07	3.51E-07	3.49E-08	3.0%	6.0	28	6.0	26	14.9
241-AN-105	2.41E-03	2.65E-07	2.88E-07	2.86E-08	2.0%	7.7	35	7.6	32	11.7
241-AN-106	4.90E-03	2.32E-07	5.62E-07	5.60E-08	0.9%	4.1	17	4.1	17	21.9
241-AN-107	7.26E-03	2.00E-07	8.95E-07	8.93E-08	0.5%	2.6	11	2.6	11	34.3
241-AP-101	5.94E-03	4.56E-07	1.60E-07	1.58E-08	1.4%	14.4	68	14.0	58	6.4
241-AP-102	4.14E-03	5.05E-07	3.08E-07	3.06E-08	2.3%	7.1	32	7.0	30	12.7
241-AP-103	4.03E-03	2.90E-07	7.02E-07	7.00E-08	1.3%	3.2	14	3.2	13	27.8
241-AP-104	5.48E-03	1.42E-07	5.31E-07	5.29E-08	0.5%	4.4	19	4.4	18	20.3
241-AP-105	2.17E-03	4.13E-07	2.11E-07	2.10E-08	3.5%	9.8	48	9.6	43	9.2
241-AP-106	5.00E-03	7.41E-08	6.12E-07	6.11E-08	0.3%	3.9	16	3.8	15	23.2
241-AP-107	7.08E-03	1.10E-06	2.78E-07	2.76E-08	2.9%	7.7	36	7.5	33	11.8
241-AP-108	6.06E-03	9.92E-07	3.34E-07	3.33E-08	3.0%	6.3	29	6.2	27	14.3
241-AW-101	3.51E-03	1.19E-08	2.08E-07	2.06E-08	0.1%	11.7	51	11.4	46	7.8
241-AW-102	7.10E-03	7.17E-08	2.89E-07	2.88E-08	0.2%	8.3	35	8.1	33	10.9
241-AW-103	2.64E-03	6.38E-07	3.18E-07	3.16E-08	4.5%	6.2	31	6.1	29	14.5
241-AW-104	5.11E-03	1.84E-07	4.76E-07	4.74E-08	0.7%	4.9	21	4.8	20	18.4
241-AW-105	1.03E-02	7.71E-07	6.89E-08	6.70E-09	1.4%	35.2	210	32.5	136	2.7
241-AW-106	4.54E-03	4.00E-07	2.24E-07	2.22E-08	1.6%	10.1	46	9.9	42	9.0
241-AY-101	2.22E-03	1.44E-07	1.77E-07	1.75E-08	1.2%	13.2	61	12.8	53	6.3
241-AY-102	5.63E-03	7.79E-08	7.18E-08	6.99E-09	0.3%	35.4	200	32.7	132	2.7
241-AZ-101	5.33E-03	1.35E-07	1.13E-07	1.11E-08	0.5%	21.7	105	20.7	84	4.3
241-AZ-102	2.70E-03	5.44E-07	5.55E-07	5.53E-08	3.7%	3.7	17	3.6	16	24.5
241-SY-101	5.69E-03	1.10E-06	2.12E-07	2.10E-08	3.6%	9.8	48	9.6	43	9.3
241-SY-102	9.14E-03	9.61E-07	1.27E-07	1.25E-08	1.9%	18.0	89	17.3	74	5.1
241-SY-103	4.62E-03	1.45E-06	5.39E-07	5.37E-08	5.8%	3.4	17	3.4	17	26.3

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-9. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.55, Temperature of 155 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	6.18E-03	1.70E-07	4.67E-07	4.65E-08	0.5%	5.0	21	4.9	20	18.0
241-AN-102	6.81E-03	2.04E-07	1.98E-06	1.97E-07	0.6%	1.2	5	1.2	5	76.5
241-AN-103	4.17E-03	3.92E-07	2.79E-07	2.77E-08	1.8%	8.0	36	7.8	33	11.4
241-AN-104	2.65E-03	3.03E-07	4.03E-07	4.01E-08	2.1%	5.4	24	5.3	23	16.7
241-AN-105	3.17E-03	2.52E-07	3.32E-07	3.30E-08	1.5%	6.8	30	6.7	28	13.4
241-AN-106	5.88E-03	2.16E-07	6.49E-07	6.48E-08	0.7%	3.5	15	3.5	14	25.3
241-AN-107	8.25E-03	1.85E-07	1.01E-06	1.01E-07	0.4%	2.3	9	2.3	9	39.0
241-AP-101	6.95E-03	4.23E-07	1.85E-07	1.83E-08	1.1%	12.5	57	12.2	50	7.3
241-AP-102	5.08E-03	4.74E-07	3.56E-07	3.54E-08	1.7%	6.2	28	6.2	26	14.5
241-AP-103	4.97E-03	2.72E-07	8.10E-07	8.09E-08	1.0%	2.8	12	2.8	11	32.0
241-AP-104	6.48E-03	1.32E-07	6.13E-07	6.11E-08	0.4%	3.8	16	3.8	15	23.5
241-AP-105	2.88E-03	3.95E-07	2.44E-07	2.42E-08	2.6%	8.8	41	8.6	38	10.3
241-AP-106	5.99E-03	6.91E-08	7.06E-07	7.04E-08	0.2%	3.3	14	3.3	13	26.9
241-AP-107	8.07E-03	1.02E-06	3.21E-07	3.19E-08	2.4%	6.7	31	6.6	29	13.4
241-AP-108	7.07E-03	9.21E-07	3.86E-07	3.85E-08	2.4%	5.6	25	5.5	24	16.2
241-AW-101	4.40E-03	1.12E-08	2.39E-07	2.37E-08	0.0%	10.1	43	9.8	39	9.0
241-AW-102	8.09E-03	6.63E-08	3.34E-07	3.32E-08	0.2%	7.1	30	7.0	28	12.7
241-AW-103	3.43E-03	6.06E-07	3.67E-07	3.65E-08	3.3%	5.6	26	5.6	25	16.0
241-AW-104	6.10E-03	1.72E-07	5.49E-07	5.47E-08	0.5%	4.2	18	4.2	17	21.2
241-AW-105	1.03E-02	7.65E-07	7.93E-08	7.74E-09	1.4%	30.0	167	28.1	117	3.2
241-AW-106	5.51E-03	3.74E-07	2.58E-07	2.56E-08	1.3%	8.8	39	8.6	36	10.3
241-AY-101	2.95E-03	1.37E-07	2.04E-07	2.02E-08	0.9%	11.4	51	11.1	46	7.2
241-AY-102	5.84E-03	7.61E-08	8.28E-08	8.09E-09	0.2%	30.1	159	28.2	113	3.2
241-AZ-101	6.32E-03	1.25E-07	1.22E-07	1.20E-08	0.4%	19.8	94	19.0	77	4.7
241-AZ-102	3.50E-03	5.17E-07	5.87E-07	5.85E-08	2.8%	3.6	16	3.6	16	25.0
241-SY-101	6.69E-03	1.02E-06	2.45E-07	2.43E-08	2.9%	8.7	41	8.5	37	10.5
241-SY-102	1.00E-02	8.86E-07	1.46E-07	1.44E-08	1.6%	15.6	75	15.0	63	5.9
241-SY-103	5.59E-03	1.35E-06	6.21E-07	6.19E-08	4.5%	3.1	15	3.1	14	28.7

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-10. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 at 62% Filled at SpG 1.55, Temperature of 150 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	6.11E-03	1.71E-07	3.64E-07	3.61E-08	0.5%	6.5	28	6.4	26	13.9
241-AN-102	6.74E-03	2.05E-07	1.54E-06	1.54E-07	0.6%	1.5	6	1.5	6	59.2
241-AN-103	4.12E-03	3.94E-07	2.19E-07	2.17E-08	1.8%	10.3	47	10.1	43	8.8
241-AN-104	2.61E-03	3.04E-07	3.15E-07	3.13E-08	2.2%	7.0	32	6.9	29	12.9
241-AN-105	3.12E-03	2.53E-07	2.59E-07	2.56E-08	1.5%	8.8	39	8.6	36	10.3
241-AN-106	5.82E-03	2.17E-07	5.05E-07	5.02E-08	0.7%	4.6	19	4.6	19	19.5
241-AN-107	8.17E-03	1.86E-07	7.99E-07	7.97E-08	0.4%	2.9	12	2.9	12	30.5
241-AP-101	6.87E-03	4.25E-07	1.45E-07	1.42E-08	1.1%	16.2	77	15.6	65	5.7
241-AP-102	5.02E-03	4.76E-07	2.77E-07	2.75E-08	1.8%	8.1	36	8.0	34	11.2
241-AP-103	4.91E-03	2.73E-07	6.30E-07	6.28E-08	1.0%	3.6	15	3.6	15	24.7
241-AP-104	6.41E-03	1.33E-07	4.77E-07	4.74E-08	0.4%	4.9	21	4.9	20	18.2
241-AP-105	2.85E-03	3.95E-07	1.91E-07	1.88E-08	2.6%	11.5	55	11.2	49	8.0
241-AP-106	5.92E-03	6.94E-08	5.50E-07	5.47E-08	0.2%	4.3	18	4.3	17	20.8
241-AP-107	8.00E-03	1.02E-06	2.51E-07	2.48E-08	2.4%	8.7	40	8.6	37	10.4
241-AP-108	6.99E-03	9.26E-07	3.01E-07	2.98E-08	2.5%	7.2	33	7.1	31	12.5
241-AW-101	4.35E-03	1.13E-08	1.87E-07	1.85E-08	0.0%	13.0	58	12.7	51	7.0
241-AW-102	8.01E-03	6.67E-08	2.60E-07	2.58E-08	0.2%	9.2	40	9.0	36	9.8
241-AW-103	3.39E-03	6.07E-07	2.86E-07	2.83E-08	3.3%	7.3	35	7.2	32	12.4
241-AW-104	6.03E-03	1.73E-07	4.28E-07	4.25E-08	0.5%	5.5	23	5.4	22	16.4
241-AW-105	1.04E-02	7.59E-07	6.28E-08	6.01E-09	1.4%	39.1	248	35.8	150	2.5
241-AW-106	5.45E-03	3.75E-07	2.02E-07	1.99E-08	1.3%	11.5	52	11.2	46	8.0
241-AY-101	2.91E-03	1.37E-07	1.59E-07	1.57E-08	0.9%	14.9	69	14.4	59	5.6
241-AY-102	6.01E-03	7.54E-08	6.54E-08	6.28E-09	0.2%	39.3	235	36.0	145	2.5
241-AZ-101	6.25E-03	1.26E-07	1.05E-07	1.03E-08	0.4%	23.4	115	22.2	90	4.0
241-AZ-102	3.45E-03	5.18E-07	4.93E-07	4.91E-08	2.8%	4.3	20	4.3	19	20.8
241-SY-101	6.62E-03	1.03E-06	1.91E-07	1.89E-08	2.9%	11.3	54	11.0	48	8.1
241-SY-102	9.96E-03	8.92E-07	1.14E-07	1.12E-08	1.7%	20.3	102	19.4	82	4.6
241-SY-103	5.53E-03	1.36E-06	4.84E-07	4.81E-08	4.6%	4.0	20	4.0	19	22.2

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-11. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.5, Temperature of 155 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	7.20E-03	1.58E-07	4.14E-07	4.12E-08	0.4%	5.7	24	5.6	23	15.9
241-AN-102	7.83E-03	1.89E-07	1.75E-06	1.75E-07	0.5%	1.3	5	1.3	5	67.3
241-AN-103	5.14E-03	3.67E-07	2.48E-07	2.46E-08	1.3%	9.2	41	9.0	37	9.9
241-AN-104	3.47E-03	2.87E-07	3.58E-07	3.56E-08	1.5%	6.3	28	6.2	26	14.4
241-AN-105	4.05E-03	2.38E-07	2.95E-07	2.93E-08	1.1%	7.8	34	7.6	32	11.7
241-AN-106	6.51E-03	2.06E-07	5.76E-07	5.74E-08	0.6%	4.0	17	4.0	16	22.3
241-AN-107	9.00E-03	1.74E-07	8.94E-07	8.92E-08	0.4%	2.6	11	2.6	10	34.3
241-AP-101	7.96E-03	3.91E-07	1.64E-07	1.62E-08	0.9%	14.3	66	13.8	57	6.4
241-AP-102	6.10E-03	4.42E-07	3.16E-07	3.14E-08	1.4%	7.2	32	7.0	29	12.6
241-AP-103	5.98E-03	2.53E-07	7.18E-07	7.16E-08	0.8%	3.2	13	3.2	13	28.1
241-AP-104	7.43E-03	1.23E-07	5.43E-07	5.41E-08	0.3%	4.3	18	4.3	17	20.8
241-AP-105	3.74E-03	3.73E-07	2.17E-07	2.15E-08	1.9%	10.3	47	10.0	43	8.9
241-AP-106	6.81E-03	6.49E-08	6.26E-07	6.24E-08	0.2%	3.8	16	3.7	15	23.8
241-AP-107	8.33E-03	9.90E-07	2.85E-07	2.83E-08	2.2%	7.6	35	7.5	32	11.8
241-AP-108	7.99E-03	8.56E-07	3.43E-07	3.41E-08	2.0%	6.4	29	6.3	27	14.1
241-AW-101	5.39E-03	1.05E-08	2.12E-07	2.10E-08	0.0%	11.4	49	11.1	44	8.0
241-AW-102	8.43E-03	6.41E-08	2.97E-07	2.95E-08	0.1%	8.0	34	7.9	32	11.3
241-AW-103	4.35E-03	5.70E-07	3.26E-07	3.24E-08	2.4%	6.6	30	6.5	28	13.7
241-AW-104	6.85E-03	1.62E-07	4.87E-07	4.85E-08	0.4%	4.8	20	4.7	19	18.8
241-AW-105	1.02E-02	7.58E-07	7.05E-08	6.86E-09	1.4%	34.0	200	31.5	132	2.8
241-AW-106	6.53E-03	3.48E-07	2.29E-07	2.27E-08	1.0%	10.1	45	9.9	41	9.0
241-AY-101	3.81E-03	1.30E-07	1.81E-07	1.79E-08	0.6%	13.0	59	12.7	52	6.3
241-AY-102	6.15E-03	7.39E-08	7.38E-08	7.19E-09	0.2%	34.1	189	31.6	127	2.8
241-AZ-101	6.86E-03	1.20E-07	1.13E-07	1.11E-08	0.3%	21.6	104	20.6	83	4.3
241-AZ-102	4.42E-03	4.86E-07	5.15E-07	5.13E-08	2.1%	4.2	19	4.2	18	21.2
241-SY-101	7.71E-03	9.46E-07	2.17E-07	2.16E-08	2.3%	10.0	47	9.8	42	9.1
241-SY-102	1.01E-02	8.70E-07	1.30E-07	1.28E-08	1.6%	17.7	86	17.0	71	5.2
241-SY-103	6.61E-03	1.26E-06	5.50E-07	5.48E-08	3.5%	3.7	17	3.7	16	24.3

Notes:

In this calculation, 20% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-12. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.6, Temperature of 155 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	5.25E-03	1.82E-07	5.21E-07	5.19E-08	0.6%	4.4	19	4.4	18	20.2
241-AN-102	5.88E-03	2.19E-07	2.21E-06	2.21E-07	0.7%	1.0	4	1.0	4	86.0
241-AN-103	3.34E-03	4.15E-07	3.11E-07	3.09E-08	2.3%	7.0	32	6.9	30	13.0
241-AN-104	2.00E-03	3.16E-07	4.50E-07	4.48E-08	3.0%	4.7	21	4.6	20	19.3
241-AN-105	2.44E-03	2.64E-07	3.70E-07	3.68E-08	2.0%	5.9	26	5.8	25	15.2
241-AN-106	4.96E-03	2.31E-07	7.24E-07	7.23E-08	0.9%	3.1	13	3.1	13	28.4
241-AN-107	7.34E-03	1.99E-07	1.14E-06	1.13E-07	0.5%	2.0	8	2.0	8	43.8
241-AP-101	6.01E-03	4.54E-07	2.06E-07	2.04E-08	1.4%	11.1	50	10.8	45	8.2
241-AP-102	4.19E-03	5.04E-07	3.96E-07	3.95E-08	2.2%	5.5	24	5.4	23	16.5
241-AP-103	4.08E-03	2.89E-07	9.04E-07	9.02E-08	1.3%	2.5	11	2.5	10	36.1
241-AP-104	5.55E-03	1.41E-07	6.84E-07	6.82E-08	0.5%	3.4	14	3.4	14	26.4
241-AP-105	2.20E-03	4.13E-07	2.72E-07	2.70E-08	3.5%	7.6	36	7.4	33	12.0
241-AP-106	5.06E-03	7.38E-08	7.88E-07	7.86E-08	0.3%	3.0	12	2.9	12	30.1
241-AP-107	7.15E-03	1.10E-06	3.58E-07	3.56E-08	2.9%	5.9	27	5.8	26	15.3
241-AP-108	6.13E-03	9.88E-07	4.31E-07	4.29E-08	3.0%	4.9	22	4.8	21	18.5
241-AW-101	3.56E-03	1.19E-08	2.66E-07	2.64E-08	0.1%	9.0	38	8.8	35	10.1
241-AW-102	7.17E-03	7.13E-08	3.72E-07	3.71E-08	0.2%	6.4	27	6.3	25	14.2
241-AW-103	2.68E-03	6.37E-07	4.09E-07	4.07E-08	4.4%	4.8	23	4.7	22	18.8
241-AW-104	5.17E-03	1.84E-07	6.13E-07	6.11E-08	0.7%	3.8	16	3.7	15	23.8
241-AW-105	1.03E-02	7.72E-07	8.82E-08	8.63E-09	1.4%	26.8	143	25.2	105	3.5
241-AW-106	4.60E-03	3.98E-07	2.88E-07	2.86E-08	1.6%	7.8	35	7.6	32	11.6
241-AY-101	2.25E-03	1.44E-07	2.28E-07	2.26E-08	1.2%	10.1	45	9.8	41	8.1
241-AY-102	5.53E-03	7.84E-08	9.21E-08	9.02E-09	0.3%	26.9	137	25.3	102	3.5
241-AZ-101	5.39E-03	1.34E-07	1.33E-07	1.31E-08	0.5%	18.1	85	17.4	71	5.1
241-AZ-102	2.74E-03	5.43E-07	6.62E-07	6.60E-08	3.7%	3.0	14	3.0	14	29.4
241-SY-101	5.76E-03	1.10E-06	2.73E-07	2.71E-08	3.6%	7.5	36	7.4	33	12.0
241-SY-102	9.22E-03	9.55E-07	1.63E-07	1.61E-08	1.9%	13.8	66	13.3	57	6.7
241-SY-103	4.68E-03	1.44E-06	6.92E-07	6.90E-08	5.8%	2.6	13	2.6	13	34.0

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-13. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.7 Temperature of 155 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	3.69E-03	2.03E-07	6.31E-07	6.29E-08	1.0%	3.6	15	3.6	15	24.9
241-AN-102	4.26E-03	2.45E-07	2.69E-06	2.68E-07	1.1%	0.8	3	0.8	3	106.2
241-AN-103	2.09E-03	4.51E-07	3.77E-07	3.75E-08	4.0%	5.3	25	5.2	24	17.0
241-AN-104	1.11E-03	3.37E-07	5.45E-07	5.43E-08	5.6%	3.4	17	3.3	16	26.6
241-AN-105	1.42E-03	2.83E-07	4.48E-07	4.46E-08	3.7%	4.5	21	4.5	20	19.9
241-AN-106	3.43E-03	2.56E-07	8.78E-07	8.76E-08	1.4%	2.5	11	2.5	11	35.2
241-AN-107	5.67E-03	2.26E-07	1.39E-06	1.38E-07	0.7%	1.7	7	1.6	7	54.1
241-AP-101	4.39E-03	5.09E-07	2.49E-07	2.47E-08	2.2%	8.8	41	8.6	37	10.3
241-AP-102	2.78E-03	5.54E-07	4.80E-07	4.78E-08	3.7%	4.2	20	4.2	19	21.3
241-AP-103	2.69E-03	3.17E-07	1.10E-06	1.09E-07	2.2%	2.0	9	2.0	8	45.5
241-AP-104	3.96E-03	1.58E-07	8.28E-07	8.27E-08	0.7%	2.8	12	2.7	11	32.3
241-AP-105	1.25E-03	4.41E-07	3.29E-07	3.27E-08	6.6%	5.3	28	5.3	27	16.9
241-AP-106	3.52E-03	8.20E-08	9.55E-07	9.53E-08	0.4%	2.4	10	2.4	10	36.8
241-AP-107	5.49E-03	1.24E-06	4.33E-07	4.32E-08	4.2%	4.6	22	4.5	21	19.7
241-AP-108	4.50E-03	1.11E-06	5.22E-07	5.20E-08	4.6%	3.7	18	3.7	17	24.2
241-AW-101	2.26E-03	1.30E-08	3.22E-07	3.20E-08	0.1%	7.4	31	7.3	29	12.2
241-AW-102	5.51E-03	8.07E-08	4.51E-07	4.49E-08	0.3%	5.2	22	5.2	21	17.2
241-AW-103	1.59E-03	6.86E-07	4.96E-07	4.94E-08	8.0%	3.2	18	3.2	17	27.7
241-AW-104	3.62E-03	2.04E-07	7.42E-07	7.41E-08	1.1%	3.0	13	3.0	13	29.3
241-AW-105	9.71E-03	8.24E-07	1.06E-07	1.04E-08	1.6%	21.8	111	20.7	87	4.3
241-AW-106	3.12E-03	4.40E-07	3.48E-07	3.46E-08	2.6%	6.1	28	6.0	26	14.7
241-AY-101	1.29E-03	1.54E-07	2.75E-07	2.73E-08	2.2%	7.9	36	7.8	33	10.3
241-AY-102	4.92E-03	8.29E-08	1.11E-07	1.09E-08	0.3%	22.0	106	21.0	85	4.2
241-AZ-101	3.82E-03	1.49E-07	1.54E-07	1.52E-08	0.7%	15.3	71	14.8	61	6.0
241-AZ-102	1.64E-03	5.85E-07	8.20E-07	8.18E-08	6.7%	2.1	11	2.1	11	42.3
241-SY-101	4.15E-03	1.23E-06	3.30E-07	3.28E-08	5.5%	5.6	29	5.6	27	16.0
241-SY-102	7.64E-03	1.09E-06	1.97E-07	1.95E-08	2.7%	11.0	52	10.7	47	8.3
241-SY-103	3.19E-03	1.59E-06	8.39E-07	8.37E-08	9.3%	1.8	10	1.8	10	50.7

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

Table B-14. Time to Lower Flammability Limit for Evaporator Vessel C-A-1 with 62% Filled at SpG 1.6, Temperature of 160 °F, 30% NH_3.

Tanks	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 hydrogen unit rate (mole/m^3 per sec)	UCH_4 methane unit rate (mole/m^3 per sec)	Steady-state NH_3 LFL (%)	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfh)
241-AN-101	5.07E-03	1.84E-07	6.67E-07	6.65E-08	0.7%	3.4	14	3.4	14	26.2
241-AN-102	5.69E-03	2.21E-07	2.82E-06	2.82E-07	0.7%	0.8	3	0.8	3	110.9
241-AN-103	3.22E-03	4.17E-07	3.97E-07	3.95E-08	2.4%	5.4	24	5.3	23	16.8
241-AN-104	1.92E-03	3.18E-07	5.75E-07	5.74E-08	3.1%	3.6	16	3.5	16	25.1
241-AN-105	2.35E-03	2.66E-07	4.75E-07	4.73E-08	2.1%	4.5	20	4.5	19	19.8
241-AN-106	4.79E-03	2.33E-07	9.30E-07	9.28E-08	0.9%	2.4	10	2.4	10	36.8
241-AN-107	7.12E-03	2.02E-07	1.44E-06	1.44E-07	0.5%	1.6	7	1.6	6	56.0
241-AP-101	5.81E-03	4.59E-07	2.63E-07	2.61E-08	1.5%	8.5	38	8.3	35	10.7
241-AP-102	4.04E-03	5.08E-07	5.08E-07	5.07E-08	2.4%	4.2	19	4.2	18	21.4
241-AP-103	3.94E-03	2.91E-07	1.16E-06	1.16E-07	1.4%	1.9	8	1.9	8	46.9
241-AP-104	5.36E-03	1.43E-07	8.77E-07	8.75E-08	0.5%	2.6	11	2.6	11	34.1
241-AP-105	2.11E-03	4.14E-07	3.49E-07	3.47E-08	3.7%	5.8	27	5.7	26	15.6
241-AP-106	4.89E-03	7.45E-08	1.01E-06	1.01E-07	0.3%	2.3	9	2.3	9	39.0
241-AP-107	6.94E-03	1.11E-06	4.59E-07	4.58E-08	3.0%	4.5	21	4.5	20	19.9
241-AP-108	5.94E-03	1.00E-06	5.53E-07	5.51E-08	3.2%	3.7	17	3.7	16	24.2
241-AW-101	3.43E-03	1.20E-08	3.40E-07	3.38E-08	0.1%	6.9	29	6.8	27	13.0
241-AW-102	6.96E-03	7.23E-08	4.78E-07	4.76E-08	0.2%	4.9	20	4.8	19	18.4
241-AW-103	2.58E-03	6.40E-07	5.26E-07	5.24E-08	4.7%	3.6	18	3.6	17	24.7
241-AW-104	5.00E-03	1.85E-07	7.86E-07	7.84E-08	0.7%	2.9	12	2.9	12	30.9
241-AW-105	9.96E-03	7.92E-07	1.13E-07	1.11E-08	1.5%	20.4	102	19.5	82	4.6
241-AW-106	4.44E-03	4.02E-07	3.69E-07	3.67E-08	1.7%	6.0	26	5.9	25	15.1
241-AY-101	2.17E-03	1.44E-07	2.92E-07	2.90E-08	1.3%	7.7	34	7.6	32	10.6
241-AY-102	5.27E-03	7.96E-08	1.18E-07	1.16E-08	0.3%	20.5	98	19.6	79	4.5
241-AZ-101	5.21E-03	1.35E-07	1.57E-07	1.55E-08	0.5%	15.1	69	14.6	59	6.1
241-AZ-102	2.63E-03	5.46E-07	7.91E-07	7.89E-08	3.9%	2.5	12	2.5	11	35.7
241-SY-101	5.57E-03	1.11E-06	3.50E-07	3.48E-08	3.7%	5.7	27	5.7	26	15.7
241-SY-102	8.98E-03	9.72E-07	2.08E-07	2.07E-08	2.0%	10.5	49	10.3	44	8.7
241-SY-103	4.51E-03	1.45E-06	8.87E-07	8.85E-08	6.1%	2.0	10	2.0	10	44.7

Notes:

In this calculation, 30% of the raw waste concentrations is ammonia, while hydrogen uses data in the targeted SpG.

It covers the off-normal condition when it occurred (i.e., lost vacuum and vent) while the process is running steadily or the process is finished.

BB = barometric breathing.

LFL = lower flammability limit.

APPENDIX C

FLAMMABILITY ANALYSIS RESULTS ON CONDENSATE TANK TK-C-100

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APPENDIX C

FLAMMABILITY ANALYSIS RESULTS ON CONDENSATE TANK TK-C-100

Table C-1. Input Data of Raw Liquid Waste for Flammability Calculation on Condensate Tank TK-C-100 (2 sheets)

Tanks	Total tank volume (ft^3)	Head-space temp (°C)	Molar specific volume (L/mole)	Filled waste fraction f	Ratio of wetted area and volume (ft^2/ft^3)	Ratio of surface area and volume (ft^2/ft^3)	Ammonia transport constant k_1 (min^{-1})	Ammonia transport constant k_2 (M/min)	U_{H2} unit rate of hydrogen ($mole/m^3$-s)	Steady-state H_2 LFL (%)	Steady-state CH_4 LFL (%)	Steady-state NH_3 LFL (%)	Steady-state LFL at BB (%)
05-01 Campaign	2,710	29	24.8	0.10	1.00	0.56	7.85E-03	1.09E-07	4.04E-09	1%	0%	0.2%	0.8%
	2,710	29	24.8	0.20	0.64	0.28	8.83E-03	1.22E-07	2.60E-09	1%	0%	0.2%	1.0%
	2,710	29	24.8	0.30	0.53	0.19	1.01E-02	1.40E-07	2.12E-09	1%	0%	0.2%	1.3%
	2,710	29	24.8	0.40	0.47	0.14	1.18E-02	1.63E-07	1.88E-09	1%	0%	0.2%	1.7%
	2,710	29	24.8	0.50	0.43	0.11	1.41E-02	1.96E-07	1.73E-09	2%	0%	0.2%	2.3%
	2,710	29	24.8	0.60	0.41	0.09	1.77E-02	2.45E-07	1.64E-09	3%	0%	0.2%	3.2%
	2,710	29	24.8	0.70	0.39	0.08	2.35E-02	3.26E-07	1.57E-09	4%	0%	0.2%	4.6%
	2,710	29	24.8	0.80	0.38	0.07	3.53E-02	4.89E-07	1.52E-09	7%	0%	0.2%	7.5%
	2,710	29	24.8	0.85	0.37	0.07	7.06E-02	9.78E-07	1.50E-09	10%	0%	0.2%	10.3%
9/3/2003 Sample	2,710	29	24.8	0.10	1.00	0.56	7.85E-03	2.89E-07	4.04E-09	1%	0%	0.6%	1.1%
	2,710	29	24.8	0.20	0.64	0.28	8.83E-03	3.25E-07	2.60E-09	1%	0%	0.6%	1.4%
	2,710	29	24.8	0.30	0.53	0.19	1.01E-02	3.71E-07	2.12E-09	1%	0%	0.6%	1.7%
	2,710	29	24.8	0.40	0.47	0.14	1.18E-02	4.33E-07	1.88E-09	1%	0%	0.6%	2.1%
	2,710	29	24.8	0.50	0.43	0.11	1.41E-02	5.20E-07	1.73E-09	2%	0%	0.6%	2.7%
	2,710	29	24.8	0.60	0.41	0.09	1.77E-02	6.50E-07	1.64E-09	3%	0%	0.6%	3.5%
	2,710	29	24.8	0.70	0.39	0.08	2.35E-02	8.67E-07	1.57E-09	4%	0%	0.6%	5.0%
	2,710	29	24.8	0.80	0.38	0.07	3.53E-02	1.30E-06	1.52E-09	7%	0%	0.6%	7.8%
	2,710	29	24.8	0.85	0.37	0.07	7.06E-02	2.60E-06	1.50E-09	10%	0%	0.6%	10.7%

Table C-1. Input Data of Raw Liquid Waste for Flammability Calculation on Condensate Tank TK-C-100 (2 sheets)

Tanks	Total tank volume (ft^3)	Head-space temp (°C)	Molar specific volume (L/mole)	Filled waste fraction f	Ratio of wetted area and volume (ft^2/ft^3)	Ratio of surface area and volume (ft^2/ft^3)	Ammonia transport constant k_1 (min^{-1})	Ammonia transport constant k_2 (M/min)	U_{H2} unit rate of hydrogen ($mole/m^3$-s)	Steady-state H_2 LFL (%)	Steady-state CH_4 LFL (%)	Steady-state NH_3 LFL (%)	Steady-state LFL at BB (%)
3 g/L NH3 Case	2,710	29	24.8	0.10	1.00	0.56	7.85E-03	1.13E-06	4.04E-09	1%	0%	2.4%	2.9%
	2,710	29	24.8	0.20	0.64	0.28	8.83E-03	1.27E-06	2.60E-09	1%	0%	2.4%	3.2%
	2,710	29	24.8	0.30	0.53	0.19	1.01E-02	1.45E-06	2.12E-09	1%	0%	2.4%	3.5%
	2,710	29	24.8	0.40	0.47	0.14	1.18E-02	1.69E-06	1.88E-09	1%	0%	2.4%	3.9%
	2,710	29	24.8	0.50	0.43	0.11	1.41E-02	2.03E-06	1.73E-09	2%	0%	2.4%	4.4%
	2,710	29	24.8	0.60	0.41	0.09	1.77E-02	2.54E-06	1.64E-09	3%	0%	2.4%	5.3%
	2,710	29	24.8	0.70	0.39	0.08	2.35E-02	3.38E-06	1.57E-09	4%	0%	2.4%	7%
	2,710	29	24.8	0.80	0.38	0.07	3.53E-02	5.07E-06	1.52E-09	7%	0%	2.4%	10%
	2,710	29	24.8	0.85	0.37	0.07	7.06E-02	1.01E-05	1.50E-09	10%	0%	2.4%	12%
6.8 g/L NH3 Case	2,710	29	24.8	0.10	1.00	0.56	7.85E-03	2.55E-06	4.04E-09	1%	0%	5.4%	5.9%
	2,710	29	24.8	0.20	0.64	0.28	8.83E-03	2.87E-06	2.60E-09	1%	0%	5.4%	6.2%
	2,710	29	24.8	0.30	0.53	0.19	1.01E-02	3.28E-06	2.12E-09	1%	0%	5.4%	6.5%
	2,710	29	24.8	0.40	0.47	0.14	1.18E-02	3.83E-06	1.88E-09	1%	0%	5.4%	6.9%
	2,710	29	24.8	0.50	0.43	0.11	1.41E-02	4.60E-06	1.73E-09	2%	0%	5.4%	7.5%
	2,710	29	24.8	0.60	0.41	0.09	1.77E-02	5.75E-06	1.64E-09	3%	0%	5.4%	8.3%
	2,710	29	24.8	0.70	0.39	0.08	2.35E-02	7.66E-06	1.57E-09	4%	0%	5.4%	10%
	2,710	29	24.8	0.80	0.38	0.07	3.53E-02	1.15E-05	1.52E-09	7%	0%	5.4%	13%
	2,710	29	24.8	0.85	0.37	0.07	7.06E-02	2.30E-05	1.50E-09	10%	0%	5.4%	15%

Notes:

BB= barometric breathing.

LFL = lower flammability limit.

Table C-2. Results of Flammability Calculation on Condensate Tank TK-C-100.

Tanks	Filled waste fraction f	Time to reach 25% LFL at BB vent (days)	Time to reach 100% LFL at BB vent (days)	Time to reach 25% LFL at zero vent (days)	Time to reach 100% LFL at zero vent (days)	Vent rate keep below 25% LFL (cfm)	Vent rate keep below 100% LFL (cfm)
05-01 Campaign	0.10	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.20	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.30	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.40	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.50	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.60	not occur	not occur	1,899	2,000	less than bb	less than bb
	0.70	not occur	not occur	1,270	2,000	less than bb	less than bb
	0.80	not occur	not occur	764	2,000	less than bb	less than bb
	0.85	not occur	not occur	547	2,000	less than bb	less than bb
9/3/2003 Sample	0.10	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.20	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.30	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.40	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.50	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.60	not occur	not occur	1,870	2,000	less than bb	less than bb
	0.70	not occur	not occur	1,251	2,000	less than bb	less than bb
	0.80	not occur	not occur	752	2,000	less than bb	less than bb
	0.85	not occur	not occur	538	2,000	less than bb	less than bb
3 g/L NH3 Case	0.10	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.20	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.30	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.40	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.50	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.60	not occur	not occur	1,733	2,000	less than bb	less than bb
	0.70	not occur	not occur	1,160	2,000	less than bb	less than bb
	0.80	not occur	not occur	698	2,000	less than bb	less than bb
	0.85	not occur	not occur	499	2,000	less than bb	less than bb
6.8 g/L NH3 Case	0.10	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.20	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.30	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.40	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.50	not occur	not occur	2,000	2,000	less than bb	less than bb
	0.60	not occur	not occur	1,501	2,000	less than bb	less than bb
	0.70	not occur	not occur	1,004	2,000	less than bb	less than bb
	0.80	not occur	not occur	605	2,000	less than bb	less than bb
	0.85	not occur	not occur	432	2,000	less than bb	less than bb

Notes:

BB or bb = barometric breathing.
LFL = lower flammability limit.

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APPENDIX D

FLAMMABILITY ANALYSIS FOR 242-A EVAPORATOR CAMPAIGNS 07-01 AND 07-02

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APPENDIX D

FLAMMABILITY ANALYSIS FOR 242-A EVAPORATOR CAMPAIGNS 07-01 AND 07-02

This appendix documents the flammability analysis performed as part of the planning for 242-A Evaporator campaigns 07-01 and 07-02 (RPP-PLAN-33127, *Process Control Plan for 242-A Evaporator Campaigns 07-01 and 07-02*). The analysis was performed to meet the requirements of 242-A Evaporator Technical Safety Requirement (TSR) administrative control (AC) 5.6.1.9 (HNF-15279).

The methodology used in this analysis is taken from RPP-5926, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, and RPP-8050, *Lower Flammability Limit Calculations for Catch Tanks, IMUSTs, DST Annuli, Pit Structures, and Double-Contained Receiver Tanks in Tank Farms at the Hanford Site*, and summarized in Chapter 6.0 of this document. The waste feed for Evaporator Campaigns 07-01 and 07-02 is described in RPP-PLAN-33127. The feed compositions are given in SVF-1315, *Generate supporting calculations for the "Process Control Plan for 242-A Evaporator Campaigns 07-01 and 07-02" (RPP-PLAN-33127).* Table D-1 and Table D-2 list the required input data for the waste feeds (taken from SVF-1315). Validated Microsoft Excel[3] spreadsheets used for the calculation are listed in Chapter 7.0.

During the campaigns, the evaporator will take feed blended from waste in tanks 241-AP-104 and 241-AW-102. The blending process is to concentrate the 241-AW-102 waste from its SpG of 1.07 to 1.28, which is the SpG of 241-AP-104 waste, before receiving 241-AP-104 waste for better mixing. This modeling effort calculates the flammability at different mixing percentages for 241-AP-104 up to 50%. Based on Equation 4-2 in the main text, the concentration ratio from SpG of 1.07 to 1.28 is 4, i.e., the concentration at SpG of 1.28 would be four times as concentrated as it is at 1.07. The input data for the gas generation calculations on various combinations of the blended wastes from 241-AP-104 (raw SpG of 1.28) and 241-AW-102 (concentrated waste at SpG of 1.28) are given in Table D-3. The raw waste of 241-AP-104 (at SpG of 1.28) and 241-AW-102 (at SpG of 1.07) are also included in Table D-3 for the flammability analysis as comparison. The flammability sensitivity analysis at various SpG and waste temperatures for different combinations of the waste feeds are performed and given in Tables D-4 through D-6. Table D-4 lists the input data and Tables D-5 and D-6 list the values of the derived terms and the results of the flammability analyses. In general, lower SpG and lower waste temperature result in increased time to 25% of the LFL.

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[3] Microsoft Excel is a trademark of Microsoft Corporation, Redmond, Washington.

References

RPP-5926, 2006, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, Rev. 6, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-8050, 2005, *Lower Flammability Limit Calculations for Catch Tanks, IMUSTs, DST Annuli, Pit Structures, and Double-Contained Receiver Tanks in Tank Farms at the Hanford Site*, Rev. 4-A, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-15279, 2006, *Technical Safety Requirements for the 242-A Evaporator*, Rev. 0-E, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-PLAN-33127, 2007, *Process Control Plan for 242-A Evaporator Campaigns 07-01 and 07-02*, Rev. 0A, CH2M HILL Hanford Group, Inc., Richland, Washington.

SVF-1315, 2007, *Generate supporting calculations for the "Process Control Plan for 242-A Evaporator Campaigns 07-01 and 07-02" (RPP-PLAN-33127)*, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table D-1. Chemical Composition of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102.

Constituent	Na (µg/mL)	Al (µg/mL)	Fe (µg/mL)	Cr (µg/mL)	Ni (µg/mL)	K (µg/mL)	TOC (µg/mL)	OH (µg/mL)	NO_2 (µg/mL)	NO_3 (µg/mL)	CO_3 (µg/mL)	PO_4 (µg/mL)	SO_4 (µg/mL)	F (µg/mL)	Cl (µg/mL)	NH_3 (µg/mL)
241-AP-104	1.28E+05	1.67E+04	5.02E+00	4.99E+02	4.59E+01	2.10E+03	4.14E+03	1.96E+04	6.37E+04	1.00E+05	1.73E+04	3.76E+03	2.12E+03	3.06E+02	5.19E+03	1.00E+03
241-AW-102	3.76E+04	1.94E+03	2.00E+00	4.02E+01	8.31E+00	7.43E+02	1.90E+03	2.92E+03	1.51E+04	1.60E+04	1.65E+04	2.53E+03	1.04E+03	2.88E+02	5.92E+02	5.63E+01

Note: 1. The feed data are taken from SVF-1315
2. TIC (total inorganic carbon) data was used to derive CO_3: (TIC x 5 = CO_3)

Table D-2. Radionuclide Composition and SpG of Liquid Feeds.

Radionuclide	Sr-89/90 (µCi/g)	Am-241 (µCi/g)	Pu-239 (µCi/g)	Pu-240 (µCi/g)	Pu-238 (µCi/g)	Cs-137 (µCi/g)	SpG (g/mL)
241-AP-104	1.32E+00	1.80E-02	1.36E-03	1.36E-03	1.04E-03	1.46E+02	1.28E+00
241-AW-102	7.86E-02	1.72E-05	1.53E-03	1.53E-03	2.42E-04	2.71E+01	1.07E+00

Note: 1. The feed data are taken from SVF-1315
2. Pu-239/240 was used for Pu-239 and for Pu-240

Table D-3. Chemical Composition and Radionuclide of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102.

Composition of Mixture Waste of 241-AP-104 and 241-AW-102	Na in Liquid [Na] (μg/mL)	Al in Liquid [Al] (μg/mL)	Fe^{+3} in Liquid (μg/mL)	Cr^{+3} in Liquid (μg/mL)	Ni^{+2} in Liquid (μg/mL)	K^{+1} in Liquid (μg/mL)	TOC in Liquid [TOC] (μg/mL)	OH^{-1} in Liquid [OH] (μg/mL)	NO_2 in Liquid [NO_2] (μg/mL)	NO_3 in Liquid [NO_3] (μg/mL)	CO_3^{-2} in Liquid (μg/mL)	PO_4^{-3} in Liquid (μg/mL)	SO_4^{-2} in Liquid (μg/mL)
Raw 241-AP-104	1.28E+05	1.67E+04	5.02E+00	4.99E+02	4.59E+01	2.10E+03	4.14E+03	1.96E+04	6.37E+04	1.00E+05	1.73E+04	3.76E+03	2.12E+03
2AW-0.25/4AP-0.75	1.33E+05	1.45E+04	5.72E+00	4.14E+02	4.26E+01	2.30E+03	4.96E+03	1.75E+04	6.26E+04	9.09E+04	2.90E+04	5.30E+03	2.61E+03
2AW-0.45/4AP-0.55	1.37E+05	1.26E+04	6.28E+00	3.45E+02	3.99E+01	2.46E+03	5.62E+03	1.59E+04	6.17E+04	8.34E+04	3.85E+04	6.53E+03	3.00E+03
2AW-0.5/4AP-0.5	1.38E+05	1.22E+04	6.42E+00	3.28E+02	3.92E+01	2.50E+03	5.79E+03	1.55E+04	6.15E+04	8.15E+04	4.08E+04	6.83E+03	3.10E+03
2AW-1.0/4AP-0.0	1.47E+05	7.60E+03	7.83E+00	1.57E+02	3.25E+01	2.91E+03	7.44E+03	1.14E+04	5.92E+04	6.27E+04	6.44E+04	9.91E+03	4.07E+03
Raw 241-AW-102	3.76E+04	1.94E+03	2.00E+00	4.02E+01	8.31E+00	7.43E+02	1.90E+03	2.92E+03	1.51E+04	1.60E+04	1.65E+04	2.53E+03	1.04E+03

Composition of Mixture Waste of 241-AP-104 and 241-AW-102	F^{-1} in Liquid (μg/mL)	Cl^{-1} in Liquid (μg/mL)	^{90}Sr in Waste [Sr] (μCi/g)	^{241}Am in Waste [Am241] (μCi/g)	^{240}Pu in Waste [Pu240] (μCi/g)	^{239}Pu in Waste [Pu240] (μCi/g)	^{238}Pu in Waste [Pu238] (μCi/g)	^{137}Cs in Waste [Cs] (μCi/g)	Liquid NH_3 (μg/mL)	Bulk Density D (g/mL)	Liquid Density DL (g/ml)	Bulk Water [H_2O] (wt%)	Liquid Water [H_2O] (wt%)
Raw 241-AP-104	3.06E+02	5.19E+03	1.32E+00	1.80E-02	1.36E-03	1.36E-03	1.04E-03	1.46E+02	1.00E+03	1.28	1.28	66%	66%
2AW-0.25/4AP-0.75	5.11E+02	4.47E+03	1.05E+00	1.35E-02	2.26E-03	2.26E-03	9.81E-04	1.32E+02	7.55E+02	1.28	1.28	65%	65%
2AW-0.45/4AP-0.55	6.75E+02	3.90E+03	8.40E-01	9.93E-03	2.99E-03	2.99E-03	9.31E-04	1.20E+02	5.58E+02	1.28	1.28	64%	64%
2AW-0.5/4AP-0.5	7.16E+02	3.75E+03	7.87E-01	9.03E-03	3.17E-03	3.17E-03	9.18E-04	1.17E+02	5.09E+02	1.28	1.28	63%	63%
2AW-1.0/4AP-0.0	1.13E+03	2.32E+03	2.57E-01	5.61E-05	4.99E-03	4.99E-03	7.92E-04	8.85E+01	1.69E+01	1.28	1.28	61%	61%
Raw 241-AW-102	2.88E+02	5.92E+02	7.86E-02	1.72E-05	1.53E-03	1.53E-03	2.42E-04	2.71E+01	5.63E+01	1.07	1.07	88%	88%

Note: The 241-AW-102 waste in the mixture waste has been concentrated from the SpG of 1.07 to 1.28 to match the SpG of 241-AP-104 for better mixing.

Table D-4. Input Data of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at Various SpG and Waste Temperature		Total Tank Volume (ft^3)	Head space Temp (°C)	Molar Specific Volume (L/mole)	Filled waste fraction f	Ratio of Wetted Area and Volume (ft^2/ft^3)	Ratio of Surface Area and Volume (ft^2/ft^3)	RCrad (mole/m^3-s) H_2 from Radiolysis	RCtherm (mole/m^3-s) H_2 from Thermolysis	N_2O Release Rate $Rr(N_2O)$ (cfm)	Ammonia Liquid Concen. (mole/L)*	Liquid Henry Constant KH (M/atm)	Ammonia Transport Coefficient h (m/sec)
SpG 1.6 and 160 °F	Raw 241-AP-104	5611	71	28.2	0.62	0.53	0.07	3.12E-08	8.26E-07	1.43E-04	1.76E-02	3.32	4.25E-06
	2AW-0.25/4AP-0.75	5611	71	28.2	0.62	0.53	0.07	3.29E-08	9.34E-07	5.53E-04	1.33E-02	2.98	4.37E-06
	2AW-0.45/4AP-0.55	5611	71	28.2	0.62	0.53	0.07	3.34E-08	1.00E-06	5.81E-03	9.83E-03	2.73	4.45E-06
	2AW-0.5/4AP-0.5	5611	71	28.2	0.62	0.53	0.07	3.35E-08	1.02E-06	4.55E-03	8.97E-03	2.68	4.47E-06
	2AW-1.0/4AP-0.0	5611	71	28.2	0.62	0.53	0.07	3.16E-08	1.08E-06	1.30E-03	2.98E-04	2.16	4.67E-06
	Raw 241-AW-102	5611	71	28.2	0.62	0.53	0.07	3.16E-08	1.08E-06	4.76E-04	9.92E-04	2.16	4.67E-06
SpG 1.7 and 155 °F	Raw 241-AP-104	5611	68	28.0	0.62	0.53	0.07	3.42E-08	7.75E-07	1.43E-04	1.76E-02	2.26	4.71E-06
	2AW-0.25/4AP-0.75	5611	68	28.0	0.62	0.53	0.07	3.62E-08	8.77E-07	5.53E-04	1.33E-02	1.99	4.82E-06
	2AW-0.45/4AP-0.55	5611	68	28.0	0.62	0.53	0.07	3.69E-08	9.41E-07	5.81E-03	9.83E-03	1.80	4.90E-06
	2AW-0.5/4AP-0.5	5611	68	28.0	0.62	0.53	0.07	3.69E-08	9.55E-07	4.55E-03	8.97E-03	1.76	4.92E-06
	2AW-1.0/4AP-0.0	5611	68	28.0	0.62	0.53	0.07	3.49E-08	1.02E-06	1.30E-03	2.98E-04	1.37	5.09E-06
	Raw 241-AW-102	5611	68	28.0	0.62	0.53	0.07	3.49E-08	1.02E-06	4.76E-04	9.92E-04	1.37	5.09E-06
SpG 1.6 and 155 °F	Raw 241-AP-104	5611	68	28.0	0.62	0.53	0.07	2.76E-08	6.40E-07	1.43E-04	1.76E-02	3.50	4.21E-06
	2AW-0.25/4AP-0.75	5611	68	28.0	0.62	0.53	0.07	2.89E-08	7.24E-07	5.53E-04	1.33E-02	3.14	4.32E-06
	2AW-0.45/4AP-0.55	5611	68	28.0	0.62	0.53	0.07	2.94E-08	7.77E-07	5.81E-03	9.83E-03	2.88	4.41E-06
	2AW-0.5/4AP-0.5	5611	68	28.0	0.62	0.53	0.07	2.94E-08	7.88E-07	4.55E-03	8.97E-03	2.82	4.43E-06
	2AW-1.0/4AP-0.0	5611	68	28.0	0.62	0.53	0.07	2.76E-08	8.39E-07	1.30E-03	2.98E-04	2.27	4.63E-06
	Raw 241-AW-102	5611	68	28.0	0.62	0.53	0.07	2.76E-08	8.39E-07	4.76E-04	9.92E-04	2.27	4.63E-06
SpG 1.6 and 150 °F	Raw 241-AP-104	5611	66	27.8	0.62	0.53	0.07	2.44E-08	4.94E-07	1.43E-04	1.76E-02	3.48	4.22E-06
	2AW-0.25/4AP-0.75	5611	66	27.8	0.62	0.53	0.07	2.55E-08	5.59E-07	5.53E-04	1.33E-02	3.12	4.34E-06
	2AW-0.45/4AP-0.55	5611	66	27.8	0.62	0.53	0.07	2.58E-08	6.00E-07	5.81E-03	9.83E-03	2.86	4.42E-06
	2AW-0.5/4AP-0.5	5611	66	27.8	0.62	0.53	0.07	2.58E-08	6.08E-07	4.55E-03	8.97E-03	2.80	4.45E-06
	2AW-1.0/4AP-0.0	5611	66	27.8	0.62	0.53	0.07	2.42E-08	6.48E-07	1.30E-03	2.98E-04	2.26	4.64E-06
	Raw 241-AW-102	5611	66	27.8	0.62	0.53	0.07	2.42E-08	6.48E-07	4.76E-04	9.92E-04	2.26	4.64E-06

Table D-4. Input Data of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at Various SpG and Waste Temperature		Total Tank Volume (ft^3)	Head space Temp (°C)	Molar Specific Volume (L/mole)	Filled waste fraction f	Ratio of Wetted Area and Volume (ft^2/ft^3)	Ratio of Surface Area and Volume (ft^2/ft^3)	RCrad (mole/m^3-s) H_2 from Radiolysis	RCtherm (mole/m^3-s) H_2 from Thermolysis	N_2O Release Rate $Rr(N_2O)$ (cfm)	Ammonia Liquid Concen. (mole/L)*	Liquid Henry Constant KH (M/atm)	Ammonia Transport Coefficient h (m/sec)
SpG 1.55 and 155 °F	Raw 241-AP-104	5611	68	28.0	0.62	0.53	0.07	2.45E-08	5.74E-07	1.43E-04	1.76E-02	4.35	3.93E-06
	2AW-0.25/4AP-0.75	5611	68	28.0	0.62	0.53	0.07	2.56E-08	6.49E-07	5.53E-04	1.33E-02	3.94	4.04E-06
	2AW-0.45/4AP-0.55	5611	68	28.0	0.62	0.53	0.07	2.59E-08	6.97E-07	5.81E-03	9.83E-03	3.64	4.13E-06
	2AW-0.5/4AP-0.5	5611	68	28.0	0.62	0.53	0.07	2.59E-08	7.07E-07	4.55E-03	8.97E-03	3.57	4.15E-06
	2AW-1.0/4AP-0.0	5611	68	28.0	0.62	0.53	0.07	2.42E-08	7.53E-07	1.30E-03	2.98E-04	2.93	4.36E-06
	Raw 241-AW-102	5611	68	28.0	0.62	0.53	0.07	2.42E-08	7.53E-07	4.76E-04	9.92E-04	2.93	4.36E-06
SpG 1.55 and 150 °F	Raw 241-AP-104	5611	66	27.8	0.62	0.53	0.07	2.17E-08	4.43E-07	1.43E-04	1.76E-02	4.32	3.95E-06
	2AW-0.25/4AP-0.75	5611	66	27.8	0.62	0.53	0.07	2.26E-08	5.01E-07	5.53E-04	1.33E-02	3.92	4.06E-06
	2AW-0.45/4AP-0.55	5611	66	27.8	0.62	0.53	0.07	2.28E-08	5.38E-07	5.81E-03	9.83E-03	3.62	4.15E-06
	2AW-0.5/4AP-0.5	5611	66	27.8	0.62	0.53	0.07	2.28E-08	5.45E-07	4.55E-03	8.97E-03	3.55	4.17E-06
	2AW-1.0/4AP-0.0	5611	66	27.8	0.62	0.53	0.07	2.12E-08	5.81E-07	1.30E-03	2.98E-04	2.91	4.37E-06
	Raw 241-AW-102	5611	66	27.8	0.62	0.53	0.07	2.12E-08	5.81E-07	4.76E-04	9.92E-04	2.91	4.37E-06
SpG 1.50 and 155 °F	Raw 241-AP-104	5611	68	28.0	0.62	0.53	0.07	2.15E-08	5.09E-07	1.43E-04	1.76E-02	5.15	3.70E-06
	2AW-0.25/4AP-0.75	5611	68	28.0	0.62	0.53	0.07	2.23E-08	5.75E-07	5.53E-04	1.33E-02	4.73	3.80E-06
	2AW-0.45/4AP-0.55	5611	68	28.0	0.62	0.53	0.07	2.26E-08	6.18E-07	5.81E-03	9.83E-03	4.42	3.88E-06
	2AW-0.5/4AP-0.5	5611	68	28.0	0.62	0.53	0.07	2.25E-08	6.27E-07	4.55E-03	8.97E-03	4.34	3.90E-06
	2AW-1.0/4AP-0.0	5611	68	28.0	0.62	0.53	0.07	2.10E-08	6.67E-07	1.30E-03	2.98E-04	3.67	4.09E-06
	Raw 241-AW-102	5611	68	28.0	0.62	0.53	0.07	2.10E-08	6.67E-07	4.76E-04	9.92E-04	3.67	4.09E-06
SpG 1.50 and 150 °F	Raw 241-AP-104	5611	66	27.8	0.62	0.53	0.07	1.91E-08	3.93E-07	1.43E-04	1.76E-02	5.14	3.71E-06
	2AW-0.25/4AP-0.75	5611	66	27.8	0.62	0.53	0.07	1.98E-08	4.44E-07	5.53E-04	1.33E-02	4.72	3.81E-06
	2AW-0.45/4AP-0.55	5611	66	27.8	0.62	0.53	0.07	1.99E-08	4.77E-07	5.81E-03	9.83E-03	4.41	3.89E-06
	2AW-0.5/4AP-0.5	5611	66	27.8	0.62	0.53	0.07	1.99E-08	4.84E-07	4.55E-03	8.97E-03	4.34	3.91E-06
	2AW-1.0/4AP-0.0	5611	66	27.8	0.62	0.53	0.07	1.84E-08	5.15E-07	1.30E-03	2.98E-04	3.66	4.10E-06
	Raw 241-AW-102	5611	66	27.8	0.62	0.53	0.07	1.84E-08	5.15E-07	4.76E-04	9.92E-04	3.66	4.10E-06

Note:
* Ammonia concentration used in flammability evaluation assumed to be 30% of original waste feed concentration.

Table D-5. Results of Flammability Calculation of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at Various SpG and Waste Temperature		Filled waste fraction f	RCcorr H_2 from Corrosion (mole/m^3-s)	Ammonia transport constant k1 (min-1)	Ammonia transport constant k2 (M/min)	UH_2 Unit rate of hydrogen (mole/m^3-s)	UCH_4 Unit rate of methane (mole/m^3-s)	Steady-state EQ NH^3 Concen. (%)	Steady State H_2 LFL (%)	Steady State CH_4 LFL (%)	Steady State NH_3 LFL (%)	Steady State LFL at B.B. (%)
SpG 1.6 and 160 °F	Raw 241-AP-104	0.62	1.88E-09	5.63E-03	1.06E-06	8.59E-07	8.57E-08	0.53	1895%	151%	3.5%	2049%
	2AW-0.25/4AP-0.75	0.62	1.88E-09	5.19E-03	8.19E-07	9.69E-07	9.67E-08	0.45	2137%	171%	3.0%	2311%
	2AW-0.45/4AP-0.55	0.62	1.88E-09	4.85E-03	6.18E-07	1.04E-06	1.04E-07	0.36	2290%	183%	2.4%	2475%
	2AW-0.5/4AP-0.5	0.62	1.88E-09	4.77E-03	5.66E-07	1.05E-06	1.05E-07	0.33	2322%	185%	2.2%	2509%
	2AW-1.0/4AP-0.0	0.62	1.88E-09	4.01E-03	1.96E-08	1.12E-06	1.11E-07	0.01	2463%	197%	0.1%	2660%
	Raw 241-AW-102	0.62	1.88E-09	4.01E-03	6.53E-08	1.12E-06	1.11E-07	0.05	2463%	197%	0.3%	2660%
SpG 1.7 and 155 °F	Raw 241-AP-104	0.62	1.89E-09	4.21E-03	1.17E-06	8.11E-07	8.09E-08	0.78	1775%	142%	5.2%	1922%
	2AW-0.25/4AP-0.75	0.62	1.89E-09	3.80E-03	9.04E-07	9.15E-07	9.13E-08	0.67	2002%	160%	4.4%	2166%
	2AW-0.45/4AP-0.55	0.62	1.89E-09	3.49E-03	6.79E-07	9.80E-07	9.78E-08	0.54	2144%	171%	3.6%	2319%
	2AW-0.5/4AP-0.5	0.62	1.89E-09	3.42E-03	6.22E-07	9.93E-07	9.92E-08	0.51	2174%	174%	3.4%	2351%
	2AW-1.0/4AP-0.0	0.62	1.89E-09	2.75E-03	2.14E-08	1.05E-06	1.05E-07	0.02	2305%	184%	0.1%	2489%
	Raw 241-AW-102	0.62	1.89E-09	2.75E-03	7.12E-08	1.05E-06	1.05E-07	0.07	2305%	184%	0.5%	2489%
SpG 1.6 and 155 °F	Raw 241-AP-104	0.62	1.89E-09	5.82E-03	1.05E-06	6.69E-07	6.68E-08	0.50	1465%	117%	3.4%	1585%
	2AW-0.25/4AP-0.75	0.62	1.89E-09	5.37E-03	8.11E-07	7.55E-07	7.53E-08	0.42	1652%	132%	2.8%	1786%
	2AW-0.45/4AP-0.55	0.62	1.89E-09	5.02E-03	6.12E-07	8.08E-07	8.06E-08	0.34	1769%	141%	2.3%	1912%
	2AW-0.5/4AP-0.5	0.62	1.89E-09	4.94E-03	5.60E-07	8.19E-07	8.18E-08	0.32	1793%	143%	2.1%	1938%
	2AW-1.0/4AP-0.0	0.62	1.89E-09	4.16E-03	1.94E-08	8.69E-07	8.67E-08	0.01	1901%	152%	0.1%	2053%
	Raw 241-AW-102	0.62	1.89E-09	4.16E-03	6.48E-08	8.69E-07	8.67E-08	0.04	1901%	152%	0.3%	2053%
SpG 1.6 and 150 °F	Raw 241-AP-104	0.62	1.91E-09	5.75E-03	1.05E-06	5.20E-07	5.18E-08	0.51	1129%	90%	3.4%	1222%
	2AW-0.25/4AP-0.75	0.62	1.91E-09	5.30E-03	8.14E-07	5.86E-07	5.84E-08	0.43	1272%	101%	2.8%	1376%
	2AW-0.45/4AP-0.55	0.62	1.91E-09	4.96E-03	6.14E-07	6.27E-07	6.26E-08	0.34	1362%	109%	2.3%	1473%
	2AW-0.5/4AP-0.5	0.62	1.91E-09	4.88E-03	5.62E-07	6.36E-07	6.34E-08	0.32	1380%	110%	2.1%	1493%
	2AW-1.0/4AP-0.0	0.62	1.91E-09	4.11E-03	1.95E-08	6.74E-07	6.72E-08	0.01	1463%	117%	0.1%	1579%
	Raw 241-AW-102	0.62	1.91E-09	4.11E-03	6.50E-08	6.74E-07	6.72E-08	0.04	1463%	117%	0.3%	1579%

Table D-5. Results of Flammability Calculation of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at Various SpG and Waste Temperature		Filled waste fraction f	RCcorr H_2 from Corrosion (mole/m^3-s)	Ammonia transport constant kl (min-1)	Ammonia transport constant k2 (M/min)	UH_2 Unit rate of hydrogen (mole/m^3-s)	UCH_4 Unit rate of methane (mole/m^3-s)	Steady-state EQ NH^3 Concen. (%)	Steady State H_2 LFL (%)	Steady State CH_4 LFL (%)	Steady State NH_3 LFL (%)	Steady State LFL at B.B. (%)
SpG 1.55 and 155 °F	Raw 241-AP-104	0.62	1.89E-09	6.76E-03	9.77E-07	6.00E-07	5.98E-08	0.40	1313%	105%	2.7%	1421%
	2AW-0.25/4AP-0.75	0.62	1.89E-09	6.30E-03	7.58E-07	6.77E-07	6.75E-08	0.34	1480%	118%	2.2%	1601%
	2AW-0.45/4AP-0.55	0.62	1.89E-09	5.95E-03	5.73E-07	7.25E-07	7.23E-08	0.27	1585%	127%	1.8%	1714%
	2AW-0.5/4AP-0.5	0.62	1.89E-09	5.86E-03	5.25E-07	7.34E-07	7.33E-08	0.25	1607%	128%	1.7%	1737%
	2AW-1.0/4AP-0.0	0.62	1.89E-09	5.05E-03	1.83E-08	7.79E-07	7.77E-08	0.01	1704%	136%	0.1%	1840%
	Raw 241-AW-102	0.62	1.89E-09	5.05E-03	6.10E-08	7.79E-07	7.77E-08	0.03	1704%	136%	0.2%	1840%
SpG 1.55 and 150 °F	Raw 241-AP-104	0.62	1.91E-09	6.69E-03	9.81E-07	4.66E-07	4.65E-08	0.41	1012%	81%	2.7%	1096%
	2AW-0.25/4AP-0.75	0.62	1.91E-09	6.23E-03	7.62E-07	5.25E-07	5.23E-08	0.34	1140%	91%	2.3%	1233%
	2AW-0.45/4AP-0.55	0.62	1.91E-09	5.88E-03	5.75E-07	5.62E-07	5.61E-08	0.27	1221%	97%	1.8%	1320%
	2AW-0.5/4AP-0.5	0.62	1.91E-09	5.80E-03	5.27E-07	5.70E-07	5.68E-08	0.25	1237%	99%	1.7%	1338%
	2AW-1.0/4AP-0.0	0.62	1.91E-09	4.99E-03	1.84E-08	6.04E-07	6.02E-08	0.01	1311%	105%	0.1%	1415%
	Raw 241-AW-102	0.62	1.91E-09	4.99E-03	6.12E-08	6.04E-07	6.02E-08	0.03	1311%	105%	0.2%	1416%
SpG 1.50 and 155 °F	Raw 241-AP-104	0.62	1.89E-09	7.51E-03	9.19E-07	5.32E-07	5.30E-08	0.34	1164%	93%	2.3%	1259%
	2AW-0.25/4AP-0.75	0.62	1.89E-09	7.10E-03	7.13E-07	6.00E-07	5.98E-08	0.28	1312%	105%	1.9%	1419%
	2AW-0.45/4AP-0.55	0.62	1.89E-09	6.77E-03	5.38E-07	6.42E-07	6.40E-08	0.22	1405%	112%	1.5%	1519%
	2AW-0.5/4AP-0.5	0.62	1.89E-09	6.70E-03	4.93E-07	6.51E-07	6.49E-08	0.21	1425%	114%	1.4%	1540%
	2AW-1.0/4AP-0.0	0.62	1.89E-09	5.93E-03	1.72E-08	6.90E-07	6.88E-08	0.01	1510%	120%	0.1%	1631%
	Raw 241-AW-102	0.62	1.89E-09	5.93E-03	5.72E-08	6.90E-07	6.88E-08	0.03	1510%	120%	0.2%	1631%
SpG 1.50 and 150 °F	Raw 241-AP-104	0.62	1.91E-09	7.47E-03	9.22E-07	4.14E-07	4.12E-08	0.34	898%	71%	2.3%	972%
	2AW-0.25/4AP-0.75	0.62	1.91E-09	7.05E-03	7.15E-07	4.66E-07	4.64E-08	0.28	1011%	81%	1.9%	1093%
	2AW-0.45/4AP-0.55	0.62	1.91E-09	6.73E-03	5.40E-07	4.99E-07	4.97E-08	0.22	1082%	86%	1.5%	1170%
	2AW-0.5/4AP-0.5	0.62	1.91E-09	6.65E-03	4.95E-07	5.05E-07	5.03E-08	0.21	1097%	87%	1.4%	1186%
	2AW-1.0/4AP-0.0	0.62	1.91E-09	5.88E-03	1.72E-08	5.35E-07	5.33E-08	0.01	1162%	93%	0.1%	1254%
	Raw 241-AW-102	0.62	1.91E-09	5.88E-03	5.74E-08	5.35E-07	5.33E-08	0.03	1162%	93%	0.2%	1255%

Notes:

B.B. = barometric breathing.
LFL = lower flammability limit.

Table D-6. Results of Time to 25% and 100% of the Lower Flammability Limit Calculation of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at various SpG and waste Temperature		Filled waste fraction f	Time to Reach 25% LFL at BB Vent (days)	Time to Reach 100% LFL at BB Vent (days)	Time to Reach 25% LFL at Zero Vent (days)	Time to Reach 100% LFL at Zero Vent (days)	Vent Rate keep Below 25% LFL DomeVol% per day	Vent Rate Keep Below 25% LFL (cfh)	Vent Rate Keep Below 100% LFL DomeVol% per day	Vent Rate Keep Below 100% LFL (cfh)
SpG 1.6 and 160 °F	Raw 241-AP-104	0.62	2.34	10.7	2.33	10.47	42.9%	38.2	9.5%	8.5
	2AW-0.25/4AP-0.75	0.62	2.13	9.5	2.12	9.34	47.1%	41.9	10.7%	9.5
	2AW-0.45/4AP-0.55	0.62	2.04	8.9	2.03	8.77	49.2%	43.8	11.4%	10.1
	2AW-0.5/4AP-0.5	0.62	2.02	8.8	2.01	8.66	49.5%	44.1	11.5%	10.3
	2AW-1.0/4AP-0.0	0.62	2.09	8.5	2.08	8.34	48.0%	42.7	12.0%	10.7
	Raw 241-AW-102	0.62	2.07	8.5	2.06	8.33	48.5%	43.1	12.0%	10.7
SpG 1.7 and 155 °F	Raw 241-AP-104	0.62	2.30	11.3	2.29	10.99	43.5%	38.7	9.1%	8.1
	2AW-0.25/4AP-0.75	0.62	2.12	10.0	2.11	9.82	47.3%	42.1	10.2%	9.1
	2AW-0.45/4AP-0.55	0.62	2.06	9.4	2.05	9.24	48.8%	43.4	10.8%	9.6
	2AW-0.5/4AP-0.5	0.62	2.05	9.3	2.04	9.14	48.9%	43.5	10.9%	9.7
	2AW-1.0/4AP-0.0	0.62	2.23	9.1	2.21	8.91	45.1%	40.1	11.2%	10.0
	Raw 241-AW-102	0.62	2.19	9.1	2.18	8.88	45.7%	40.6	11.3%	10.0
SpG 1.6 and 155 °F	Raw 241-AP-104	0.62	3.06	14.0	3.04	13.57	32.9%	29.3	7.4%	6.6
	2AW-0.25/4AP-0.75	0.62	2.78	12.5	2.76	12.11	36.2%	32.2	8.3%	7.3
	2AW-0.45/4AP-0.55	0.62	2.65	11.7	2.64	11.37	37.8%	33.6	8.8%	7.8
	2AW-0.5/4AP-0.5	0.62	2.64	11.5	2.62	11.23	38.1%	33.9	8.9%	7.9
	2AW-1.0/4AP-0.0	0.62	2.71	11.1	2.69	10.81	37.1%	33.0	9.2%	8.2
	Raw 241-AP-104	0.62	2.69	11.1	2.67	10.79	37.4%	33.3	9.3%	8.2
SpG 1.6 and 150 °F	2AW-0.25/4AP-0.75	0.62	3.97	18.4	3.94	17.61	25.4%	22.6	5.7%	5.1
	2AW-0.45/4AP-0.55	0.62	3.61	16.3	3.58	15.72	27.9%	24.8	6.4%	5.7
	2AW-0.5/4AP-0.5	0.62	3.45	15.3	3.43	14.76	29.1%	25.9	6.8%	6.0
	2AW-1.0/4AP-0.0	0.62	3.43	15.1	3.40	14.59	29.3%	26.1	6.9%	6.1
	Raw 241-AW-102	0.62	3.53	14.5	3.50	14.06	28.5%	25.4	7.1%	6.3
	Raw 241-AP-104	0.62	3.50	14.5	3.47	14.03	28.8%	25.6	7.1%	6.3

Table D-6. Results of Time to 25% and 100% of the Lower Flammability Limit Calculation of Liquid Feeds from Double-Shell Tanks 241-AP-104 and 241-AW-102. (2 sheets)

Mixed Waste Case at various SpG and waste Temperature		Filled waste fraction f	Time to Reach 25% LFL at BB Vent (days)	Time to Reach 100% LFL at BB Vent (days)	Time to Reach 25% LFL at Zero Vent (days)	Time to Reach 100% LFL at Zero Vent (days)	Vent Rate keep Below 25% LFL DomeVol% per day	Vent Rate Keep Below 25% LFL (cfh)	Vent Rate Keep Below 100% LFL DomeVol% per day	Vent Rate Keep Below 100% LFL (cfh)
SpG 1.55 and 155 °F	Raw 241-AP-104	0.62	3.52	15.8	3.49	15.25	28.6%	25.5	6.6%	5.8
	2AW-0.25/4AP-0.75	0.62	3.18	14.0	3.16	13.59	31.6%	28.1	7.4%	6.5
	2AW-0.45/4AP-0.55	0.62	3.03	13.1	3.01	12.74	33.2%	29.5	7.8%	7.0
	2AW-0.5/4AP-0.5	0.62	3.00	13.0	2.98	12.59	33.5%	29.8	7.9%	7.1
	2AW-1.0/4AP-0.0	0.62	3.03	12.4	3.01	12.07	33.2%	29.5	8.3%	7.4
	Raw 241-AW-102	0.62	3.01	12.4	2.99	12.05	33.4%	29.7	8.3%	7.4
SpG 1.55 and 150 °F	Raw 241-AP-104	0.62	4.57	20.7	4.53	19.78	22.1%	19.6	5.1%	4.5
	2AW-0.25/4AP-0.75	0.62	4.14	18.4	4.10	17.64	24.4%	21.7	5.7%	5.0
	2AW-0.45/4AP-0.55	0.62	3.94	17.2	3.90	16.55	25.6%	22.8	6.0%	5.4
	2AW-0.5/4AP-0.5	0.62	3.91	17.0	3.87	16.35	25.8%	22.9	6.1%	5.4
	2AW-1.0/4AP-0.0	0.62	3.94	16.3	3.91	15.69	25.5%	22.7	6.4%	5.7
	Raw 241-AW-102	0.62	3.92	16.2	3.88	15.66	25.7%	22.9	6.4%	5.7
SpG 1.50 and 155 °F	Raw 241-AP-104	0.62	4.05	18.0	4.01	17.27	24.9%	22.2	5.8%	5.2
	2AW-0.25/4AP-0.75	0.62	3.65	15.9	3.62	15.39	27.6%	24.5	6.5%	5.8
	2AW-0.45/4AP-0.55	0.62	3.47	14.9	3.44	14.42	29.0%	25.8	6.9%	6.2
	2AW-0.5/4AP-0.5	0.62	3.43	14.7	3.41	14.24	29.3%	26.1	7.0%	6.2
	2AW-1.0/4AP-0.0	0.62	3.42	14.1	3.39	13.62	29.4%	26.2	7.3%	6.5
	Raw 241-AW-102	0.62	3.40	14.0	3.38	13.60	29.6%	26.3	7.4%	6.5
SpG 1.50 and 150 °F	Raw 241-AP-104	0.62	5.26	23.6	5.20	22.40	19.2%	17.1	4.5%	4.0
	2AW-0.25/4AP-0.75	0.62	4.75	20.9	4.70	19.97	21.2%	18.9	5.0%	4.5
	2AW-0.45/4AP-0.55	0.62	4.51	19.6	4.47	18.73	22.4%	19.9	5.3%	4.7
	2AW-0.5/4AP-0.5	0.62	4.47	19.3	4.43	18.50	22.6%	20.1	5.4%	4.8
	2AW-1.0/4AP-0.0	0.62	4.46	18.5	4.41	17.70	22.6%	20.1	5.6%	5.0
	Raw 241-AW-102	0.62	4.44	18.4	4.39	17.68	22.7%	20.2	5.7%	5.0

Notes:
BB = barometric breathing. LFL = lower flammability limit.

APPENDIX E

FLAMMABILITY ANALYSIS FOR 242-A EVAPORATOR UNDER SHUTDOWN MODE AND WATER STARTUP OPERATION

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APPENDIX E

FLAMMABILITY ANALYSIS FOR 242-A EVAPORATOR UNDER SHUTDOWN MODE AND WATER STARTUP OPERATION

In shutdown mode, the C-A-1 evaporator vessel and recirculation loop are allowed to contain 10,000 gal water, antifoaming agents (AFA), process condensate, and/or inhibited water (i.e., water treated with hydroxide and/or nitrites used for corrosion control) which may be added to support maintenance or testing activities. For startup of the 242-A Evaporator, the C-A-1 evaporator vessel is filled with water, heated up, and AFA is added prior to receiving waste feed.

This appendix documents the evaluations to calculate the times to 25% and 100% of the lower flammability limit (LFL) for the 242-A Evaporator vessel under the following bounding conditions:

- 10,000 gal of process condensate in the C-A-1 evaporator vessel mixed with 165 gal of AFA at room temperature (59 °F) during the shutdown mode
- C-A-1 evaporator vessel filled with process condensate (26,000 gal) mixed with 165 gal of AFA at 160 °F for the water startup mode for evaporator operation prior to introduction of liquid waste feed.
- In both analyses, 165 gal AFA liquid is used because 165 gal is the estimated upper bounding volume for the AFA addition for each evaporator vessel fill.

The calculation shows that the time to reach 25% of the LFL at zero ventilation is longer than 1,000 days for both conditions. The inhibited water case has been evaluated, and the conclusion is that the time to 25% of the LFL is bounded by the process condensate case calculations.

The methodology used in this analysis is taken from RPP-5926, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, and RPP-8050, *Lower Flammability Limit Calculations for Catch Tanks, IMUSTs, DST Annuli, Pit Structures, and Double-Contained Receiver Tanks in Tank Farms at the Hanford Site*, and summarized in Chapter 6.0 of this document. Gas generation rate calculation uses the process condensate sample results of 242-A Evaporator 06-01 campaign (RPP-PLAN-27610, *Process Control Plan for 242-A Evaporator Campaigns 06-CR (Cold Run)*, and Tank Waste Information Network System (TWINS) database, condensate sample, September 5, 2006). The input data for gas generation rate calculations are given in Table E-1. In the input data preparation, the concentrations of chemicals and radionuclides, the density and the weight percent water conservatively are assumed the same as for process condensate except the TOC, which is a weighted averaged of the process condensate and AFA liquid concentrations. The validated Microsoft Excel[4] spreadsheets listed in Chapter 7.0 are used for both gas generation rate

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[4] Microsoft Excel is a trademark of Microsoft Corporation, Redmond, Washington.

calculations and flammability analyses. Tables E-2 and E-3 list the calculated unit generation rates of thermolysis and radiolysis. Table E-4 lists the input data and Tables E-5 and E-6 list the calculation results of the flammability analyses.

As shown in Table E-3, the hydrogen generation rate is dominated by the corrosion rate since the process condensate is low in TOC and low in radionuclides. As shown in Table E-4, for both cases, the time to reach 25% of the LFL under zero ventilation is greater than 1,000 days (note that the calculation is terminated at 2,000 days). For the inhibited water case, the zero radiation dose and low ammonia concentration will result in the generation of less gas compared to process condensate waste, thus it is bounded by the process condensate calculations. Overall, the low radiation dose and low gas generation rate of the process condensate results in low flammability and takes more than 2 years to reach 25% of the LFL.

References

RPP-5926, 2006, *Steady-State Flammable Gas Release Rate Calculation and Lower Flammability Level Evaluation for Hanford Tank Waste*, Rev. 6, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-8050, 2005, *Lower Flammability Limit Calculations for Catch Tanks, IMUSTs, DST Annuli, Pit Structures, and Double-Contained Receiver Tanks in Tank Farms at the Hanford Site*, Rev. 4-A, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-PLAN-27610, 2006, *Process Control Plan for 242-A Evaporator Campaigns 06-CR (Cold Run)*, Rev. 0B, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table E-1a. Chemical Composition of the Process Condensate for the Shutdown Mode and Startup Mode.

	Na (µg/mL)	Al (µg/mL)	Fe (µg/mL)	Cr (µg/mL)	Ni (µg/mL)	K (µg/mL)	TOC (µg/mL)	OH (µg/mL)	NO_2 (µg/mL)	NO_3 (µg/mL)	CO_3 (µg/mL)	PO_4 (µg/mL)	SO_4 (µg/mL)	F (µg/mL)	Cl (µg/mL)	NH_3 (µg/mL)
Shutdown mode	1.15E-01	3.70E-02	1.00E-03	1.00E-03	1.00E-03	1.00E-03	2.16E+03	1.66E-04	6.08E-02	1.13E-01	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.49E+02
Startup mode	1.15E-01	3.70E-02	1.00E-03	1.00E-03	1.00E-03	1.00E-03	8.36E+02	1.66E-04	6.08E-02	1.13E-01	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.00E-03	1.49E+02

Notes:

1. The process condensate data are taken from 06-01 campaign sample data, except that the TOC is an average of 55 gal of AFA liquid and process condensate.
2. Total inorganic carbon (TIC) data was used to derive CO_3: (TIC x 5 = CO_3)

Table E-1b. Radionuclide Composition and SpG for the Shutdown Mode and Startup Mode.

Radio nuclide & SpG	Sr-89/90 (µCi/g)	Am-241 (µCi/g)	Pu-239 (µCi/g)	Pu-240 (µCi/g)	Pu-238 (µCi/g)	Cs-137 (µCi/g)	SpG (g/mL)	wt% Water
Shutdown mode	0.00E+00	1.05E-09	6.40E-10	6.40E-10	0.00E+00	8.37E-07	1.01	99%
Startup mode	0.00E+00	1.05E-09	6.40E-10	6.40E-10	0.00E+00	8.37E-07	1.01	99%

Notes:

1. The process condensate data are taken from 06-01 campaign sample data.
2. Pu-239/240 was used for Pu-239 and for Pu-240.

Table E-2. Derived Data for Hydrogen Generation Rate Model Calculations for the Shutdown Mode and Startup Mode.

Tank	Total mass M (kg)	Liquid in waste (wt%)	Wetted area A_{wet} (ft^2)	Heat load per kg H_L b/r (watt/kg)	Tank heat load[b/r] H_L (watt)	Tank heat load[a] H_L alpha (watt/kg)	NO_3 in liquid $[NO_3]_M$ (mole/L)	NO_2 in liquid $[NO_2]_M$ (mole/L)	Excess Na in liquid $[Na]_{ex}$ (mole/mL)	OH in liquid [OH] (mole/L)	TOC in liquid $[TOC]_\%$ (wt%)	Al in liquid $[Al]_\%$ (wt%)
Shutdown mode	3.82E+04	100%	1846	3.96E-12	1.51E-07	7.35E-14	1.82E-06	1.32E-06	1.86E-06	1.66E-04	0.21	3.66E-06
Startup mode	3.82E+04	100%	1846	3.96E-12	1.51E-07	7.35E-14	1.82E-06	1.32E-06	1.86E-06	1.66E-04	0.08	3.66E-06

Note:
TOC = total organic carbon.

Table E-3. Calculated G Value and Hydrogen Generation Rate as Mole Per Unit Waste Weight and Volume for the Shutdown Mode and Startup Mode.

Tank	E_{H2} Efficiency of H_2 by corrosion	G values for water $G_{H2O}{}^{b/r}$ (H_2/100eV)	Total G values $G_{TOT}{}^{b/r}$ (H_2/100eV)	G values for water $G_{H2O}{}^{alpha}$ (H_2/100eV)	Total G values $G_{TOT}{}^{alpha}$ (H_2/100eV)	HGR from radiolysis $RC_{rad}{}^{b/r}$ (mole/kg-d)	HGR from radiolysis $RC_{rad}{}^{alpha}$ (mole/kg-d)	HGR from thermolysis RC_{therm} (mole/kg-d)	HGR from radiolysis $RC_{rad}{}^{b/r}$ (mole/m^3-s)	HGR from radiolysis $RC_{rad}{}^{alpha}$ (mole/m^3-s)	HGR from thermolysis RC_{therm} (mole/m^3-s)
Shutdown mode	0.50	0.45	0.45	1.40	1.40	1.60E-14	9.21E-16	1.89E-10	1.87E-16	1.08E-17	2.21E-12
Startup mode	0.50	0.45	0.47	1.40	1.41	1.67E-14	9.28E-16	3.28E-08	1.95E-16	1.08E-17	3.83E-10

Note:
HGR = hydrogen generation rate.

Table E-4. Condensate Liquid Waste for Input Data for Flammability Calculation on Shutdown and Startup Modes for the 242-A Evaporator C-A-1 Vessel.

Tanks	Total Tank Volume (ft^3)	Head space Temp (°C)	Molar Specific Volume (L/mole)	Filled waste fraction f	Ratio of Wetted Area and Volume (ft^2/ft^3)	Ratio of Surface Area and Volume (ft^2/ft^3)	RC_{rad} (mole/m^3-s) H_2 from Radiolysis	RC_{therm} (mole/m^3-s) H_2 from Thermolysis	N_2O Release Rate $Rr(N_2O)$ (cfm)	Ammonia Liquid Concen. (mole/L)	Liquid Henry Constant K_H (M/atm)	Ammonia Transport Coefficient h (m/sec)
Shutdown mode	5611	15	28.2	0.24	0.74	0.19	1.98E-16	2.21E-12	1.87E-03	8.75E-03	98.9	4.88E-06
Startup mode	5611	71	28.2	0.62	0.53	0.07	2.06E-16	3.83E-10	1.87E-03	8.75E-03	10.0	4.88E-06

Table E-5. Results of Flammability Calculation on Shutdown and Startup Modes for the 242-A Evaporator C-A-1 Vessel.

Tanks	Filled waste fraction f	RC_{corr} H2 from Corrosion (mole/m^3-s)	Ammonia transport constant k_1 (min^{-1})	Ammonia transport constant k_2 (M/min)	U_{H2} Unit rate of hydrogen (mole/m^3-s)	U_{CH4} Unit rate of methane (mole/m^3-s)	Steady-state EQ NH_3 Concen. (%)	Steady State H_2 LFL (%)	Steady State CH_4 LFL (%)	Steady State NH_3 LFL (%)	Steady State LFL at B.B. (%)
Shutdown mode	0.24	3.12E-09	1.34E-01	5.02E-07	3.12E-09	2.21E-13	0.01	1.1%	0.00%	0.1%	1.2%
Startup mode	0.62	1.88E-09	1.61E-02	5.02E-07	2.26E-09	3.83E-11	0.09	5.0%	0.07%	0.6%	5.6%

Notes:

BB or bb = barometric breathing.
LFL = lower flammability limit.

Table E-6. Results of Time to 25% and 100% of the LFL Calculation on Shutdown and Startup Modes for the 242-A Evaporator C-A-1 Vessel.

Tanks	Filled waste fraction f	Time to Reach 25% LFL at BB vent (days)	Time to Reach 100% LFL at BB vent (days)	Time to Reach 25% LFL at Zero vent (days)	Time to Reach 100% LFL at Zero vent (days)	Vent Rate keep below 25% LFL DomeVol% per day	Vent rate keep below 25% LFL (cfh)	Vent Rate keep below 100% LFL DomeVol% per day	Vent rate keep below 100% LFL (cfh)
Shutdown mode	0.24	not occur	not occur	2000	2000	0.45%	L.T. bb	0.45%	L.T. bb
Startup mode	0.62	not occur	not occur	1079	1755	0.45%	L.T. bb	0.45%	L.T. bb

Notes:

Note: The calculation is terminated at 2,000 days.
BB or bb = barometric breathing.
LFL = lower flammability limit.
L.T. = less than.

APPENDIX F

ESTIMATE OF CARBON FRACTION IN DOW CORNING 1520 SILICONE ANTIFOAM

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APPENDIX F

ESTIMATE OF CARBON FRACTION IN DOW CORNING 1520 SILICONE ANTIFOAM

K. R. Sandgren

In order to evaluate the flammable gas generation rate in the evaporator vessel it is necessary to know the organic carbon content. An additive is sometimes used to prevent foaming in the evaporator vessel. The additive is Dow Corning 1520 Silicone Antifoam. To estimate the organic carbon in the evaporator vessel, the carbon content of the anti-foaming additive must be known. Dow Corning 1520 Silicone Antifoam is a proprietary product and its exact makeup is unknown.

The material safety data sheet (MSDS) for the product provides some information. The MSDS lists the following constituents:

Component Name	**Weight %**
Water	> 60.0
Polydimethylsiloxane	15.0 – 40.0
Methylated silica	1.0 – 5.0
Methylcellulose	1.0 – 5.0

These estimates can be improved by examining the product information sheet (available at the Dow Corning website) for the anti-foaming agent. The product information sheet says the additive is "20% active silicone emulsion." Thus a best estimate of polydimethylsiloxane (PDMS) in the additive would be 20 wt%. The product information sheet also says that the total "non-volatile content" of the product is 24 wt%. Thus it can be concluded that the total amount of methylcellulose and methylated silica in the product is 4%.

PDMS is commonly defined as $(H_3C)[SiO(CH_3)_2]_nSi(CH_3)_3$ where n is the number of monomers in the polymer. This definition assumes the common form of PDMS. To be precise PDMS is $(R)[SiO(CH_3)_2]_nSi(R')(R'')(R''')$ where R, R', R'', and R''' are any of a number of carbon groups. For the analysis that follows, methyl groups will be assumed since that is the most common form of PDMS.

In order to estimate the carbon content of PDMS the number of monomers in the polymer must be known. To maximize the carbon content, the number of monomers will be assumed to be two. The carbon fraction of $(H_3C)[SiO(CH_3)_2]_2Si(CH_3)_3$ can now be estimated using the atomic weights of the constituents.

PDMS carbon fraction (where n=2)

$$[(8)(12.01)] / [(8)(12.01) + (3)(28.09) + (2)(16.00) + (24)(1.008)] = 0.406$$

where:

(8)(12.01) = (number of carbon atoms)(atomic weight of carbon)

(3)(28.09) = (number of silicon atoms)(atomic weight of silicon)

(2)(16.00) = (number of oxygen atoms)(atomic weight of oxygen)

(24)(1.008) = (number of hydrogen atoms)(atomic weight of hydrogen).

As the number of polymers increases the carbon fraction decreases to as low as 0.324.

The carbon fraction of methylated silica and methylcellulose can be estimated similarly where methylated silica is H_3CSiO_2 and methylcellulose is cellulose $(C_6H_{10}O_5)_n$ with as many as three hydroxyl groups (OH) of each monomer having the hydrogen atoms replaced with methyl groups (CH_3) forming (OCH_3). In order to maximize the carbon fraction, it is assumed that all three available hydroxyl groups have been replaced. Thus, methylcellulose is $(C_9H_{16}O_5)_n$. Since the fraction of carbon in methylated silica is much less than that in the methylcellulose, the remaining 4% of non-volatile content will be assumed to be methylcellulose. The carbon fraction of methylcellulose can now be estimated.

Methylcellulose carbon fraction

$$[(9)(12.01)] / [(9)(12.01) + (16)(1.008) + (5)(16.00)] = 0.529$$

where:

(9)(12.01) = (number of carbon atoms)(atomic weight of carbon)

(16)(1.008) = (number of hydrogen atoms)(atomic weight of hydrogen)

(5)(16.00) = (number of oxygen atoms)(atomic weight of oxygen).

Note that the number of monomers doesn't matter in methylcellulose since the proportions of all the constituents remain the same as the chain length grows.

The total organic content of the anti-foaming additive can now be estimated using the carbon fractions calculated above:

Weight percent total organic content

$$(20\text{ wt\%})(0.406) + (4\text{ wt\%})(0.529) = 10\ \%$$

where:

20 wt%	= weight percent of PDMS
0.406	= carbon fraction in PDMS
4 wt%	= weight percent remaining non-volatile content (methylcellulose)
0.529	= carbon fraction in methylcellulose.

However, there is uncertainty in this value. It is possible that the PDMS polymer could be terminated with carbon groups other than methyl groups (vinyl groups are also common but other groups are possible). If it is assumed that the polymer is terminated with vinyl groups (C_2H_3) the carbon fraction can be similarly calculated. The carbon fraction of $(H_3C_2)[SiO(CH_3)_2]_2Si(C_2H_3)_3$ is estimated as:

PDMS carbon fraction (where n=2)

$$[(12)(12.01)] / [(12)(12.01) + (3)(28.09) + (2)(16.00) + (24)(1.008)] = 0.506.$$

The total organic content assuming vinyl groups can now be estimated using the carbon fractions calculated above:

Weight percent total organic content

$$(20 \text{ wt\%})(0.506) + (4 \text{ wt\%})(0.529) = 12.2\ \%$$

where:

20 wt%	= weight percent of PDMS
0.506	= carbon fraction in vinyl terminated PDMS
4 wt%	= weight percent remaining non-volatile content (methylcellulose)
0.529	= carbon fraction in methylcellulose.

It is unlikely that the carbon fraction would be modified beyond this for an antifoaming application since the solubility of the PDMS would decrease as long chained carbon groups are substituted into the termination points. However, to conservatively account for this uncertainty the total organic content in the anti-foaming additive will be rounded up to 13%.

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APPENDIX G

TECHNICAL BASIS WHY ASSUMING ONE DRUM OF ANTIFOAMING AGENT IN THE C-A-1 EVAPORATOR VESSEL IS REASONABLY CONSERVATIVE

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APPENDIX G

TECHNICAL BASIS WHY ASSUMING ONE DRUM OF ANTIFOAMING AGENT IN THE C-A-1 EVAPORATOR VESSEL IS REASONABLY CONSERVATIVE

J. M. Conner

Assuming that there is one drum (55 gal) of antifoaming agent (AFA) (20% active Dow Corning 1520-US) in the 242-A Evaporator C-A-1 vessel (26,000 gal) is considered reasonably conservative based on the following.

- **Maximum Injection Rate** – The maximum injection rate is 0.1 gal/min and the minimum dilution allowed per procedure is one part water to one part AFA by volume (or 50% dilution). Therefore, the injection time for one drum (55 gal) at the maximum injection rate is over 18 hours. The actual injection rate is typically much lower.

- **Steady State** – Assuming production of slurry at 33 gal/min (the low slurry flow alarm set point), approximately 35,000 gal of slurry would be processed through the 242-A Evaporator in 18 hours. That is, at steady state, the maximum injection rate and the minimum slurry rate result in an AFA concentration of less than one drum/C-A-1 evaporator vessel volume. The slurry rate is usually higher, and the injection rate is usually lower.

- **Recycle Experience** – Foaming problems were anticipated in the 07-01 campaign based on the boil-down. In addition, the campaign processing strategy included recycle of dilute slurry back to the feed tank for reconcentration. Seven drums of AFA were used in "Phase 1" of Campaign 07-01, when slurry was recycled to 241-AW-102. Double-shell tank 241-AW-102 was reduced to 139 in. With 11 in. of solids, that is 128 in. of supernatant or approximately 350,000 gal. So the ratio of AFA to feed was approximately one drum/50,000 gal. At slurry conditions, the ratio would be almost one drum/C-A-1 evaporator vessel volume. However, that feed was mixed with fresh feed from 241-AP-104 before being fed to the 242-A Evaporator.

- **Startup and Recirculation** – Whenever slurry is not being discharged and AFA is being injected, the AFA concentration in the system is increasing. Two of these times are during startup and when in recirculation. Startup and recirculation could go for days. Practically, however, AFA injection during these times is limited, as the injection rate during startup is below the maximum, and the practice is to shut off AFA when in recirculation.

Therefore, an assumption of one drum of AFA in the C-A-1 evaporator vessel (26,000 gal) is reasonably conservative with the expected AFA concentration in the C-A-1 evaporator vessel below this.

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APPENDIX H

CALCULATION REVIEW CHECKLIST

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APPENDIX H

CALCULATION REVIEW CHECKLIST

RPP-CALC-29700 REV 1

Calculation Review Checklist.

Calculation Reviewed: RPP-CALC-29700, Rev. 1

Scope of Review: Main text and new/updated input data listed for flammability evaluations
(e.g., document section or portion of calculation)

Engineer/Analyst: T. A. Hu Albert Hu Date: 9-6-07

Organizational Manager: N. W. Kirch NWKirch Date: 9-6-07

This document consists of 123 pages and the following attachments (if applicable):

Yes	No	NA*		
[X]	[ ]	[ ]	1.	Analytical and technical approaches and results are reasonable and appropriate.
[X]	[ ]	[ ]	2.	Necessary assumptions are reasonable, explicitly stated, and supported.
[ ]	[ ]	[X]	3.	Ensure calculations that use software include a paper printout, microfiche, CD ROM, or other electronic file of the input data and identification to the computer codes and versions used, or provide alternate documentation to uniquely and clearly identify the exact coding and execution process.
[X]	[ ]	[ ]	4.	Input data were checked for consistency with original source information.
[ ]	[ ]	[X]	5.	Key input data (e.g., dimensions, performance characteristics) that may affect equipment design is identified.
[X]	[ ]	[ ]	6.	For both qualitative and quantitative data, uncertainties are recognized and discussed.
[ ]	[ ]	[X]	7.	Mathematical derivations were checked, including dimensional consistency of results.
[X]	[ ]	[ ]	8.	Calculations are sufficiently detailed such that a technically qualified person can understand the analysis without requiring outside information.
[ ]	[ ]	[X]	9.	Software verification and validation are addressed adequately.
[X]	[ ]	[ ]	10.	Limits/criteria/guidelines applied to the analysis results are appropriate and referenced.
[X]	[ ]	[ ]	11.	Conclusions are consistent with analytical results and applicable limits.
[X]	[ ]	[ ]	12.	Results and conclusions address all points in the purpose.
[X]	[ ]	[ ]	13.	Referenced documents are retrievable or otherwise available.
[X]	[ ]	[ ]	14.	The version or revision of each reference is cited, as appropriate.
[ ]	[ ]	[ ]	15.	The document was prepared in accordance with Attachment A, "Calculation Format and Preparation Instructions."
[ ]	[ ]	[X]	16.	Impacts on requirements have been assessed and change documentation initiated to incorporate revisions to affected documents, as appropriate.
[ ]	[ ]	[X]	17.	The design media matches the calculations.
[X]	[ ]	[ ]	18.	All checker comments have been dispositioned.

K. D. Fowler KDFowler 9/6/07
Checker (printed name and signature) Date

* If No or NA is chosen, an explanation must be provided on or attached to this form.

RPP-CALC-29700 REV 1

Calculation Reviewed: RPP-CALC-29700, Rev. 1

Item	Comment
3	Only new/revised input data as documented in text is included in scope of review. Spreadsheets are referenced in the document text, however, review does not have access to files.
5	The purpose of this calculation is not equipment design. The calculation models potential flammable gas generation and accumulation in the existing 242-A facility.
7	No new mathematical derivations included in this revision. Models were previously derived in HNF-3851, RPP-5926, and RPP-8050.
9	Software verification and validation were not included in the review scope. Review does not have access to files.
16	This calculation supports the 242-A Evaporator DSA. Results/conclusions used to support DSA changes have been reviewed by NS&L. In accordance with TFC-ENG-SB-C-01, safety basis changes are prepared by NS&L.
17	Reviewer does not have access to electronic files used for calculation.
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Calculation Review Checklist.

Calculation Reviewed: RPP-CALC-29700, Rev. 1

Scope of Review: Three drum AFA addition calculation check
(e.g., document section or portion of calculation)

Engineer/Analyst: T. A. Hu [signature] Date: 10-30-07

Organizational Manager: N. W. Kirch [signature] Date: 10-30-07

This document consists of _____ pages and the following attachments (if applicable):

Yes	No	NA*		
[X]	[]	[]	1.	Analytical and technical approaches and results are reasonable and appropriate.
[X]	[]	[]	2.	Necessary assumptions are reasonable, explicitly stated, and supported.
[]	[]	[X]	3.	Ensure calculations that use software include a paper printout, microfiche, CD ROM, or other electronic file of the input data and identification to the computer codes and versions used, or provide alternate documentation to uniquely and clearly identify the exact coding and execution process.
[X]	[]	[]	4.	Input data were checked for consistency with original source information.
[]	[]	[X]	5.	Key input data (e.g., dimensions, performance characteristics) that may affect equipment design is identified.
[]	[]	[X]	6.	For both qualitative and quantitative data, uncertainties are recognized and discussed.
[]	[]	[X]	7.	Mathematical derivations were checked, including dimensional consistency of results.
[X]	[]	[]	8.	Calculations are sufficiently detailed such that a technically qualified person can understand the analysis without requiring outside information.
[]	[]	[X]	9.	Software verification and validation are addressed adequately.
[]	[]	[X]	10.	Limits/criteria/guidelines applied to the analysis results are appropriate and referenced.
[X]	[]	[]	11.	Conclusions are consistent with analytical results and applicable limits.
[X]	[]	[]	12.	Results and conclusions address all points in the purpose.
[X]	[]	[]	13.	Referenced documents are retrievable or otherwise available.
[X]	[]	[]	14.	The version or revision of each reference is cited, as appropriate.
[]	[]	[X]	15.	The document was prepared in accordance with Attachment A, "Calculation Format and Preparation Instructions."
[]	[]	[X]	16.	Impacts on requirements have been assessed and change documentation initiated to incorporate revisions to affected documents, as appropriate.
[]	[]	[X]	17.	The design media matches the calculations.
[X]	[]	[]	18.	All checker comments have been dispositioned.

J. Jo [signature] 10/30/07
Checker (printed name and signature) Date

* If No or NA is chosen, an explanation must be provided on or attached to this form.

Calculation Reviewed: RPP-CALC-29700, Rev. 1

Item	Comment
3	Only new/revised input data as documented in text is included in scope of review. Spreadsheets are referenced in the document text, however, review does not have access to files.
5	The purpose of this calculation is not equipment design. The calculation models potential flammable gas generation and accumulation in the existing 242-A facility.
7	No new mathematical derivations included in this revision. Models were previously derived in HNF-3851, RPP-5926, and RPP-8050.
9	Software verification and validation were not included in the review scope. Review does not have access to files.
16	This calculation supports the 242-A Evaporator DSA. Results/conclusions used to support DSA changes have been reviewed by NS&L. In accordance with TFC-ENG-SB-C-01, safety basis changes are prepared by NS&L.
17	Reviewer does not have access to electronic files used for calculation.
-----	Only three drum AFA addition calculation was checked.